FAST MEMORIES

IEEE SPECTRUM

IT HAD TO BE YOU

The art and science of identity verification

FEBRUARY 1994 THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, INC.

Newslog

DEC 6. Motif Inc., Wilsonville, Ore., a joint venture of **Motorola Inc.** and **In Focus Systems Inc.,** said it had signed an agreement with **Tottori Sanyo,** Tokyo, to start the first volume production of advanced flat-panel displays in the United States. Motif's active-addressing microchips enable inexpensive passive-matrix displays to handle full-motion color video. Tottori will use the chips to make its own screens and supply liquid-crystal screens for Motif to complete with its active-addressing chips.

DEC 7. Ameritech Corp., Chicago, said it had asked the **U.S. Justice Department** for permission to start a test offering of long-distance service in 1995. The proposed trial would begin in Illinois, then be phased into use in the four other states the company serves. If the plan is approved, Ameritech would become the first Baby Bell to enter the US $60 billion long-distance market.

DEC 7. Southwestern Bell Corp., San Antonio, Texas, and **Cox Enterprises Inc.,** Atlanta, Ga., said they would form a $4.9 billion partnership to exploit cable-television, telephone, and interactive-media opportunities in each other's markets. Southwestern will invest $1.6 billion in 40 percent of Cox Cable, and Cox Cable will contribute its 21 cable systems, which are valued at $3.3 billion, serving 1.6 million subscribers.

DEC 7. France Telecom and Germany's **Deutsche Bundespost Telekom** announced a $1.14 billion joint venture to provide data and other advanced business services to multinational companies. The new venture is to begin operating early in 1995.

DEC 8. Xerox Corp., Stanford, Conn., said it would cut more than 10 000 jobs—nearly 10 percent of its workforce—over the next three years to improve productivity. The cuts will be made by attrition, layoffs, and voluntary programs. About half the cuts will be made this year.

DEC 8. Hughes Aircraft Co., Los Angeles, said it had applied to the Federal Communications Commission for permission to build a $660 million satellite system to penetrate the telephone services market. The system, called Spaceway, would be able to handle over 11 500 simultaneous two-way video, data, or voice transmissions.

DEC 9. Engineers and physicists at the **Princeton Plasma Physics Laboratory** in New Jersey said they had produced for the first time in the United States more than 3 MW of fusion power in a magnetically confined plasma consisting of deuterium and tritium. Follow-on experiments two days later in the lab's Tokamak Fusion Test Reactor produced 6.1 MW of fusion power in 0.75-second pulses, outdistancing the 2 MW of fusion power in 2-second pulses achieved in 1991 by the Joint European Torus in England. [See "Nuclear fusion advances," pp. 31–36.]

DEC 9. Texas Instruments Inc., Dallas, said it had demonstrated a quantum-mechanical semiconductor device that operates not cryogenically but at room temperature. Because electrons acting like waves can be directed by filters rather than circuitry, some parts of the device can be shrunk by 98 percent, enabling it to work three times as fast as conventional chips.

DEC 9. Telecom Australia said it had placed equipment orders worth $1.63 billion with France's **Alcatel NV,** Germany's **Siemens AG,** and Sweden's **L.M. Ericsson** as part of a five-year program to digitize its network.

DEC 10. The **National Aeronautics and Space Administration (NASA)** said that astronauts aboard the space shuttle Endeavour had released the **Hubble Space Telescope** into space after repairs involving five 6-hour spacewalks. Officials said it was the most complex orbital repair job ever undertaken, during which new components were installed to extend the telescope's life and correct its blurred vision.

DEC 13. Two groups of computer and telecommunications companies announced that they would begin work on standardizing how computers talk to each other on the future information superhighway. The **Cross Industry Working Team,** consisting of 28 companies and organized by the Corporation for National Research Initiatives, Reston, Va., will focus on techniques that enable different types of computers and networks to share information. A 16-member group known as **Collaboratory,** created by Bellcore, Livingston, N.J., will work on practical applications.

DEC 13. Loral Corp., New York City, said it would pay $1.58 billion for **IBM Corp.'s Federal Systems Co.,** whose products include software for radar-warning systems, antisubmarine warfare, satellites, and air-traffic control. The acquisition follows Loral's earlier purchase of LTV Corp.'s missile unit in 1992 and Ford Aerospace in 1990.

DEC 15. Corning Inc., Corning, N.Y., said it and its joint venture with **Siemens AG, Siecor,** would pay $130 million for the optical-fiber and optical-cable assets of Canada's **Northern Telecom Ltd.,** most of which are in Saskatoon, Sask. The purchase would give Corning access to the growing market for optical-fiber communications systems in Canada and in the 90 other countries where Northern Telecom has operations.

DEC 15. NASA announced plans for a spacecraft that would be the first to orbit an asteroid. The project will initiate a new program to fly smaller, simpler, and cheaper space science missions. The unmanned spacecraft is to be launched toward the asteroid Eros in February 1996, arriving there in December 1998. Its goal is to measure Eros's size and study its composition, geology, and magnetic fields for a year or more.

DEC 16. The **United States** and **Russia** announced they had formally become partners in an international space station and said that a Russian astronaut would fly for the first time in the space shuttle Discovery in six weeks. The pact, ending decades of rivalry, calls for an orbiting space laboratory involving the United States, Russia, Europe, Japan, and Canada to be operating by 2001.

DEC 19. Ameritech Corp. and **Deutsche Bundespost Telekom** said they had won the bidding to acquire a 30 percent stake in the Hungarian state telephone company **Matav** for $875 million. Officials said the purchase is one of the biggest privatization deals in Eastern Europe. The consortium will provide domestic long-distance and international phone service for the next eight years, as well as local service in 29 of 56 regions in Hungary. Ameritech said only 10–12 percent of Hungarians have a phone line.

Preview:

FEB 20–26. National Engineers Week will celebrate the theme "Engineers: Turning Ideas into Reality." A record 35 000 engineers are to visit schools to emphasize science and math studies. For information, contact IEEE–United States Activities at 202-789-2200 or National Engineers Week at 703-684-2852.

Sally Cahur

FEBRUARY 1994 / VOLUME 31 / NUMBER 2

IEEE SPECTRUM

SPECIAL REPORT

22 Biometric identification

By BENJAMIN MILLER

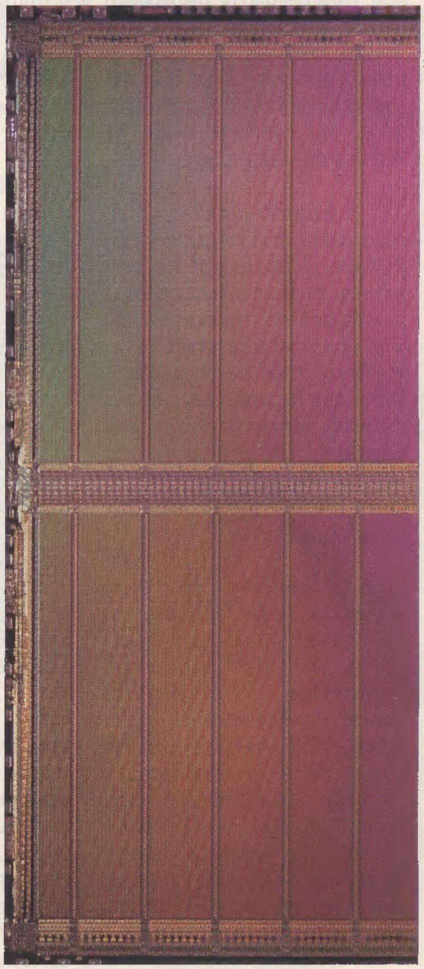
Recognition Systems Inc

Growing demands for quick and sure-fire means of verifying identity have led to automated identification systems that rely on physical or behavioral characteristics: biometrics. This overview of the field includes detailed technical descriptions of many of the latest biometric recognition devices, including systems that identify people from their faces, the irises of their eyes, their voices, fingerprints, and hands—the specialty of the device from Recognition Systems Inc., shown at left.

TUTORIAL

38 Speeding up system memory

By BETTY PRINCE



Motorola Inc.

As systems' appetites for data increase, fast innovative RAM architectures, such as the 8-ns, 1-Mb static RAM from Motorola [above], keep pace. Wider memories, the use of multiple banks on a single chip, and synchronous dynamic RAMs, like the new Jedec standard design, are helping to enhance the effective system speed. The incorporation of static RAMs directly onto microprocessors or dynamic RAM chips is simplifying memory architectures.

PERSPECTIVE

31 Nuclear fusion

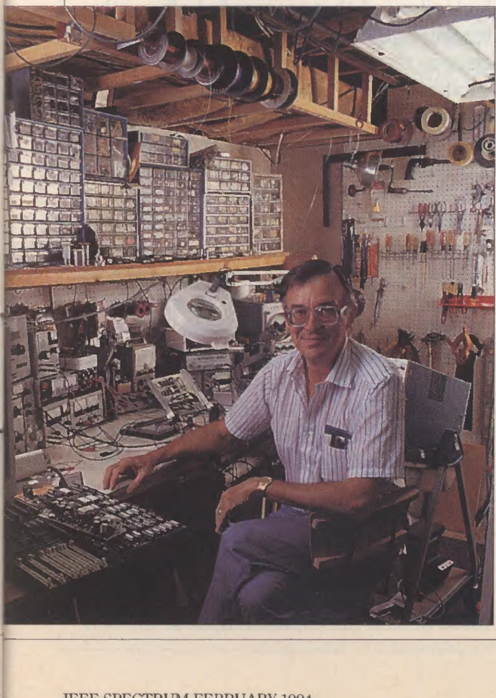
By WILLIAM SWEET

On Dec. 11, 1993, physicists and engineers at the Princeton Plasma Physics Laboratory in New Jersey produced 6.1 MW of nuclear fusion power in 0.75-second pulses from deuterium-tritium fuel. Started on Dec. 9, the experiments were the first in the United States to use this fuel. Other leading nuclear fusion facilities include General Atomics Inc.'s DIII-D tokamak in San Diego, Calif., shown during inspection [right]. Both scientific and political challenges lie ahead for the international nuclear fusion community.

General Atomics Inc.

COMMUNICATIONS

PROFILE



Jon Brenneis

Cover: The iris of that eye peering out of an ID card is unique enough to be used to verify a person's identity. This photo by Bill Simone illustrates what an ID card of the future might look like. Gus Sauter did the cover design. See p. 22.

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Forum

Against EMI

As immediate past president of the IEEE Electromagnetic Compatibility Society, I read with interest the letter by Leslie C. Hale on "In-flight EMI" [December, p. 6]. If he is not already a member of the EMC Society, I suggest he join it and share with us his knowledge and ideas for solving EMI problems. He would also be welcome to work within the IEEE EMC Society Standards Committee and the ANSI-accredited National Standards Committee C63 to help write better measurement standards for non-aerospace equipment.

Those concerned with the problem could also join in the efforts of committee AE-4 of the Radio Technical Commission for Aeronautics and Society of Automotive Engineers (RTCA and SAE, respectively) to write better EMI measurement standards for aerospace equipment. Some contacts are: EMC Society Standards Committee, David L. Traver, secretary (619-673-2601); American Society for Cybernetics C63, Nancy A. Blair, IEEE Standards Department, secretary (908-562-3801; n.blair@ieee.org); SAE AE-4, Dwayne R. Awerkamp, immediate past chairman (602-441-3138; he may be able to provide the best contact in RTCA also).

Edwin L. Bronaugh
Austin, Texas

The risks of power

Engineers currently working on superconducting design ["Superconducting wire gets hotter," December, pp. 26–30] should consider recent findings on the link between low-frequency magnetic fields and both cancer and leukemia, especially in children. The Paul Brodeur exposé, "Currents of Death," excoriated by power company officials, has triggered much diversionary research by the Electric Power Research Institute, apparently intended to stall any strong findings of health effects.

Recent massive Swedish research, endorsed by the national government, is resulting in a revamping of power distribution near schools and homes. So far there is little funding in the United States for independent research into the risks of low-frequency magnetic fields to humans, though much episodic information and several wrongful-death suits are accumulating.

The advent of much more powerful magnetic fields from very large currents in high-temperature superconductors should suggest that much attention be paid to field cancellation designs as well as to placement of these conductors in the vicinity of humans. Field strengths of only 2 milligauss have been shown to cause a doubling of the rate of leukemia in children, according to the Swedish data. A similar result was found in the Denver study by Ruth Wirtheimer in 1987. Seven years have now passed, and very little has been done to confirm her results and to take appropriate action.

I believe the IEEE should encourage independent research on this risk.

John G. Sinclair Jr.
Little River, Calif.

GPS: varied views

In the article "The Global Positioning System" by Ivan A. Getting [December, pp. 36–38, 43–47], Fig. 5 on p. 45 does not reflect the control segment of GPS as it exists today. When I compare this figure to one that appeared in a paper presented at the IEEE 1976 Position, Location and Navigation Symposium ("The GPS Control Segment and Its Service to the GPS User," by Hurley, Kramer, and Thornburg), I see so much similarity that I am forced to conclude that Getting used the 1976 paper as his source of information. In 1976, however, GPS was in its concept validation phase, and the initial control segment in operation at that time was quite different from the operational control segment that was developed during the full-scale engineering development phase (1980–87) and is in operation today.

Laura Burkhardt
Arlington, Mass.

This article misrepresents the development of the GPS. I have been involved with the GPS program from the Navy side since the beginning. I was also on the Collier committee representing the U.S. Naval Research Laboratory. I would not like to diminish the contributions of the Aerospace Corp. to the GPS, but on the other hand they should not be overstated at the expense of others who contributed. Navy developments were not stimulated by Aerospace Corp. work, and the GPS system design was not their sole work.

Ron Beard
Washington, D.C.

Historians are seldom surprised to find that singular events have a more complex genesis than the reports thereof by individuals suggest. So it is with the initial conception of the GPS-Navstar system.

In the 1950s, in directing the development of the Atlas intercontinental ballistic missile, the Air Force's Western Development Division (WDD) concluded that a radio guidance subsystem should be pursued to back up the preferred inertial guidance approach. I assembled a group of professionals to explore the influence that the atmosphere would have on its accuracy. We established a UHF "missile" transmitter at the summit of Pike's Peak, and measured its signals in the Garden of the Gods [both in Colorado]. James Fletcher (later to become twice administrator of the National Aeronautics and Space Administration) represented WDD's interests. I then advanced the concept of using multiple elevated transmitters to provide navigation and position-fixing signals to him, and we discussed it several times.

While head of the Air Force Cambridge Research Center's Communications Laboratory (soon after Sputnik was orbited), I explored this possibility with the AF R&D Command. But they were only interested in pursuing the use of satellites for communication, so it was set aside.

In 1963 I joined OSD's Defense Research and Engineering office. Soon thereafter I outlined the possibility of using multiple satellites to provide global three-dimensional navigation signals—which would be very accurate, immediate, and reliable—to engineers at The Johns Hopkins University's Applied Physics Laboratory who were working on the Navy's Transit development program. But OSD concluded that Transit, Loran, and Omega would meet its requirements.

This conclusion soon changed. In speaking with tactical air commanders in Vietnam, I became convinced that we could not strike "the iron bridge with the iron bomb" satisfactorily, and that we needed all-weather landing capabilities, especially on aircraft carriers in the South China Sea. Also, we had established a 16-satellite space segment at near-geosynchronous altitude for global voice communications and thereby become more confident about using large numbers of satellites for tactical military purposes.

I then spoke directly with several Defense R&D leaders about taking on the early development of a space-based navigation and position-fixing system. Ivan Getting, who headed the Aerospace Corp., immediately expressed keen interest in seeing his organization do so. I encouraged him, and the Air Force, to move out quickly. I also urged the creation of a surface-based test and demonstration system, to give pilots and air commanders a sense of the character and value of an eventual space-based system, and pressed for consideration of a differential signal measurement approach for carrier landing.

In his article, Getting is said to be "the force behind the establishment of the Nav-

star Global Positioning System." He certainly was that. Without his determined efforts over a considerable time we could still be awaiting its use. But its conceptual origins were somewhat different than he describes.

T. F. Rogers
McLean, Va.

More on the flat-panel past

The excellent article "The flat panel's future" by Kenneth I. Werner [November, pp. 18–26] mentioned me in regard to flat-panel displays. The Aiken Thin Cathode-Ray Tube was produced in small quantities from 1956 to 1961 in a 14-inch size, 2 5/8 inches thick, flat, with TV quality. Color was achieved in a 17-inch model. A transparent model shaped to fit military aircraft windshields was flown in 1956. Photographs are available. Volume production was not obtained because of nontechnical reasons. Peter A. Keller's book *The Cathode-Ray Tube* provides details.

William Ross Aiken
Murphys, Calif.

Diagnoses on line

I appreciate D. John Doyle's concern about my suggestion that personal computers with expert medical diagnostic and prescriptive systems be installed in public libraries to cut the cost and improve the quality of universal health care [November, p. 6].

This suggestion assumes that more-or-less optimal recommendations for treatment could be based on truthful answers to a series of objective queries so structured by expert diagnosticians as to systematically identify the medical cause of most patients' complaints. Please keep in mind that the proposed expert system would direct its users to consult with a "real doctor" for an unspecified fraction of cases that truly require nonstandard treatments.

The objective is not to complete a diagnosis and prescribe a treatment in every instance; essentially it is to provide immediate, expert guidance in treating common complaints with self-therapy and medications dispensed through a pharmacist or over the counter. The approach is consistent with the grand U.S. ethic that individuals are responsible for their own well-being.

Emerging technology will provide the public with ready access to reams of highly technical medical studies plus promotions by competing pharmaceutical companies. The public is ill equipped to make use of this deluge of information and biased advice without expert guidance. When making decisions concerning treatment of common ailments, John Q. Public already self-diagnoses and treats common ailments using immediately available information and over-the-counter medicines. The usefulness of expert systems should be viewed in terms of continually improving the quality of low-cost self-treatment of an increasing range of common complaints, as well as promoting early identification of serious diseases or complications that warrant consultation with one or more medical specialists.

Should a patient who takes the same description of symptoms to several doctors expect different diagnoses and treatments? If the symptoms are assessed objectively, and the physicians are equally familiar with the optimal treatments for the range of related ailments, one would expect little difference between their diagnoses and treatments (or well-designed expert systems that embody the corporate expertise of the medical community). One would expect an ethical doctor (or expert system) to consult with a specialist when the symptoms reported lead to an ambiguous diagnosis or an ailment for which no standard treatment has been established. The same principle would apply in development of the proposed expert system. Surely clinical diagnostic procedures are sufficiently refined to systematically identify many common ailments and prescribe appropriate treatments for them. Beyond those common ailments, an ethical expert system must prescribe consultation with a real doctor.

Paul T. Burnett
Alamogordo, N.M.

Wider horizons

Having read Robert W. Lucky's essay "Technology isn't the problem" [November, p. 14] and being something of both an engineer and a philosopher, I would like to say that engineers should treat their success at solving technological problems as an opportunity to broaden their scope. We should start a discipline in "Social Engineering." If management is going to hold endless meetings on what to do now that engineering has solved all the technical problems, why not advocate an engineering study of how new technology will offer new ways of living? Sony Corp. has been praised for its ability to create market niches (whilst having the products to fill the niches ready in advance). The task of social engineering should be set apart from the liberal arts tradition and at a higher level than ergonomics.

It is common knowledge that the air-conditioned home led to the demise of the front porch. Likewise the automobile has made the shopping mall the primary consumer purchasing location. Now, the electronic highway and the continuing decrease in electronics costs offer plenty of possibilities for the future. And the companies that can predict or influence the future social structure will make a lot of money. The problem is that the business game (that is, the evolution of products and the way they are used) is often neither efficient nor productive of optimal results. There are attempts to gain market share, to protect intellectual property; and it often takes a long time for old ways to change. I am not advocating any sort of government control or orchestration, rather I am saying that the methodology for social "re-engineering" is lacking or untaught.

James C. Brakefield
San Antonio, Texas

The origin of VR

I remember making up the phrase myself, and in the last decade I had never heard of an earlier use of it before Richard Bach's account [December, p. 6]. Virtual reality (VR) was intended to emphasize the social nature of shared (networked) virtual worlds, and to emphasize that one's own body was in the world as well as in the external environment. The common phrase prior to VR was "virtual environment," which to me emphasized the external environment too much. Standard usage was that VEs had single users and VRs had multiple simultaneous users.

At this point VR is certainly overused, and often criticized as a confused concoction of words. I agree of course that it *is* confused, yet it has that mojo that captured a bit of why people get so excited about this stuff.

My old company, VPL, owned the trademark for the term "Virtual Reality" for a time, but as I felt it was becoming part of the vernacular and did not want to fight about its ownership, we gave it to the public domain in 1988 or so.

Jaron Lanier
San Francisco, Calif.

According to Silicon Mirage: The Art and Science of Virtual Reality *by Steve Aukstakalnis and David Blatner (Peachpit Press, Berkeley, Calif., 1992), the term "virtual reality (VR)" was coined by Jaron Lanier, founder of VPL Research, in 1989. For more information on virtual reality, see* IEEE Spectrum, *January, p. 21.*—Ed.

Readers are invited to comment in this department on material previously published in *IEEE Spectrum*; on the policies and operations of the IEEE; and on technical, economic, or social matters of interest to the electrical and electronics engineering profession. Short, concise letters are preferred. The Editor reserves the right to limit debate on controversial issues. Contact: Forum, *IEEE Spectrum*, 345 E. 47th St., New York, NY 10017, U.S.A.; fax, 212-705-7453. The e-mail (Internet) address is n.hantman@ieee.org. The computer bulletin board number is 212-705-7308; the password is SPECTRUM. The line parameters are 1200 bits per second, no parity, 8 data bits, and 1 stop bit. For more information, call 212-705-7305 and ask for the Author's Guide.

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Calendar

FEBRUARY

10th Semiconductor Thermal Measurement and Management Symposium—Semi-Therm (CHMT); Feb. 1–3; Red Lion Hotel, San Jose, Calif.; Bonnie Crystall, C/S Communications Inc., Box 23899, Tempe, AZ 85285; 602-625-0700.

15th Aerospace Applications Conference (AES); Feb. 5–12; Mountain Haus, Vail, Colo.; Chuck Zamites, 1719 Morgan Lane, Redondo Beach, CA 90278.

Digital Video Compression on Personal Computers: Algorithms and Technologies Conference (C); Feb. 6–10; San Jose Convention Center, California; Jane Lybecker, SPIE, Box 10, Bellingham, WA 98227–0010; 206-676-3290; e-mail, janel@mom.spie.org; or Arturo A. Rodriguez, Kaleida Labs; e-mail, aar@kaleida.com.

High-Speed Networking and Multimedia Computing Conference (C); Feb. 6–10; San Jose Convention Center, California; Jane Lybecker, SPIE, Box 10, Bellingham, WA 98227–0010; 206-676-3290; e-mail, janel@mom.spie.org; or Arturo A. Rodriguez, Kaleida Labs; e-mail, aar@kaleida.com.

Basque International Workshop on Information Technology (C); Feb. 7–9; Hotel Athlanthal, Biarritz, France; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1992; 202-371-1013.

Second CAD-Based Vision Workshop (C); Feb. 8–10; Seven Springs Mountain Resort, Champion, Pa.; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1992; 202-371-1013; fax, 202-728-0884.

Applied Power Electronics Conference and Exposition—APEC '94 (IA, PEL); Feb. 13–17; Walt Disney World Resort, Orlando, Fla.; Pamela Wagner, Courtesy Associates, 655 15th St., S.W., Suite 300, Washington, DC 20005; 202-639-4990.

Network Operations and Management Symposium (COM); Feb. 14–18; Hyatt Orlando Hotel, Kissimmee, Fla.; Jill Pancio, Pacific Bell, Room 100, 7620 Convoy Court, San Diego, CA 92111; 619-268-6135; fax, 619-292-1509.

10th International Conference on Data Engineering (C); Feb. 14–18; Doubletree Hotel, Houston, Texas; IEEE Computer Soci-

(Continued on p. 11)

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ngland College, Springfield,
32-1344; fax, 413-782-1746.

Conference on Expert
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ngton, DC 20036-1992; 202-
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Conference on Micro-
t Structures (ED); March
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esia Blvd., Suite 12-101,
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9733; fax, 408-765-9206.

Symposium on Intelligent Systems in Communications and Power (COM, PEL); Feb. 21–23; Mayaguez Hilton, Puerto

town Heights, NY 10598; 914-945-2586; fax, 914-945-4469.

Networks for Personal Communications—NPC '94 (NJ Coast); March 16–18;

Symposium on Electromagnetic Compatibility (SCV/EMCC); March 29–30; Santa Clara Convention Center, California;

(Continued on p. 50)

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Digital Video Compressio[...] Computers: Algorithms [...] gies Conference (C); Feb. [...] Convention Center, Califo[...] becker, SPIE, Box 10, B[...] 98227-0010; 206-676-3290; e-mail, janet@ mom.spie.org; or Arturo A. Rodriguez, Kaleida Labs; e-mail, aar@kaleida.com.

High-Speed Networking and Multimedia Computing Conference (C); Feb.

Applied Power Electronics Conference and Exposition—APEC '94 (IA, PEL); Feb. 13–17; Walt Disney World Resort, Orlando, Fla.; Pamela Wagner, Courtesy Associates, 655 15th St., S.W., Suite 300, Washington, DC 20005; 202-639-4990.

[...] submit conferences for listing to: Ramona Foster, *IEEE Spectrum*, 345 E. 47th St., New York, NY 10017; 212-705-7305.

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Calendar

(Continued from p. 8)

ety, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1992; 202-371-1013; fax, 202-728-0884.

International Solid-State Circuits Conference—ISSCC '94 (SSC, SF Section, et al.); Feb. 16–18; San Francisco Marriott, San Francisco; Diane S. Suiters, Courtesy Associates Inc., 655 15th St., N.W., Suite 300, Washington, DC 20005; 202-639-4255; fax, 202-347-6109.

Conference on Optical Fiber Communication—OFC '94 (COM, LEO); Feb. 20–25; San Jose Convention Center, California; IEEE/LEOS, 445 Hoes Lane, Box 1331, Piscataway, NJ 08855-1331; 908-562-3893; fax, 908-562-1571.

Non-Volatile Semiconductor Memory Workshop (ED); Feb. 21–23; Hyatt Regency Hotel, Monterey, Calif.; Gregory E. Atwood, Intel Corp., 2220 Mission College Blvd., MS RNB3-01, Santa Clara, CA 95052; 408-765-9733; fax, 408-765-9206.

Symposium on Intelligent Systems in Communications and Power (COM, PEL); Feb. 21–23; Mayaguez Hilton, Puerto Rico; Hamed Parsiani, Technical Program Chairman, Department of Electrical and Computer Engineering, University of Puerto Rico, Mayaguez, PR 00681-5000; 809-832-4040, ext. 3653; fax, 809-831-7564.

MARCH

Columbia Basin Technical Conference and Trade Show (Richland Section); March 7–8; Red Lion Inn, Pasco, Wash.; A. Wayne Akerson, Box 1075, Richland, WA 88352; 509-373-1939; fax, 509-373-4362.

Symposium on Computer-Aided Control Systems Design—CSD (CS); March 7–9; Tucson Convention Center, Arizona; Paul Baltes, Engineering Professional Development, Box 9, Harvill Building, University of Arizona, Tucson, AZ 85721; 602-621-5104; fax, 602-621-1443.

Multi-chip Module Conference (ED); March 15–18; The Cocoanut Grove, Santa Cruz, Calif.; David P. LaPotin, IBM Thomas J. Watson Research Center, Box 218, Yorktown Heights, NY 10598; 914-945-2586; fax, 914-945-4469.

Networks for Personal Communications—NPC '94 (NJ Coast); March 16–18; Ocean Place Hilton, Long Branch, N.J.; Vijay K. Varma, Bellcore, 3X-325, 331 Newman Springs Rd., Red Bank, NJ 07701-7040; 908-758-2811; fax, 908-758-4371.

20th Northeast Bioengineering Conference (EMB); March 17–18; Western New England College, Springfield, Mass.; James V. Masi, Department of Electrical Engineering, Western New England College, Springfield, MA 01119; 413-782-1344; fax, 413-782-1746.

International Conference on Expert Systems for Development (C); March 18–21; Asian Institute of Technology, Bangkok, Thailand; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1992; 202-371-1013; fax, 202-728-0884.

International Conference on Microelectronic Test Structures (ED); March 22–24; Catamaran Resort Hotel, San Diego, Calif.; Sandra Grawet, All About Meetings Inc., 2301 Artesia Blvd., Suite 12-101, Redondo Beach, CA 90278; 310-371-3438; fax, 310-371-1567.

Symposium on Electromagnetic Compatibility (SCV/EMCC); March 29–30; Santa Clara Convention Center, California;

(Continued on p. 50)

Books

The universe, bright and dark

William I. Newman

Through a Universe Darkly. *Bartusiak, Marcia, HarperCollins, New York, 1993, 351 pp., US $27.50.*

Many fine books have been written on the origin and fate of the universe. This book, however, approaches the topic from a unique and important perspective by asking, "What is the most outstanding question in astronomy?" Consequently, it provides the reader with a sense of how lasting this subject is.

The author has an advanced degree in physics and is the recipient of the prestigious Science Writing Award from the American Institute of Physics. She is also a contributing editor of *Discover* magazine. *Through a Universe Darkly* is an easy read for a professional engineer—although intellectually a profoundly challenging one!

Since human beings first began to record history, our perspective of our place in the universe has undergone many revolutionary changes. Today, we are seemingly in the midst of yet another such change. Unlike the philosophers of classical Greece, though, we are able to formulate and test hypotheses with a vast array of instrumentation, spanning much of the range of the electromagnetic spectrum.

One theme that has surfaced several times during the past two millennia is the possible existence of an all-pervasive medium. In classical times, Aristotle inferred that the four elements of earth, air, fire, and water required a fifth essence to separate the material world from the distant heavens. This was ether, a term derived from the Greek word meaning "to ignite" or "to burn." To other philosophers, the ether seemed to be essential to the execution of motion—a consequence of paradoxes that were later resolved by the invention of calculus.

Ether then re-emerged with the discovery of gravitational and electromagnetic forces; to some, forces had to be mediated by something, even if it had no mass or other physical attributes. The special theory of relativity effectively put the matter to rest when Einstein showed that the ether, if it existed, had no influence upon electromagnetic waves—or else the earth was not moving. Our place in the universe seemed secure, and the need for the ether evaporated.

In the 1920s, astronomers came to realize that the Milky Way was but one galaxy in a cosmos containing billions of such island universes. One of their principal investigative tools was the so-called virial theorem, which related the amount of potential energy to the kinetic energy present in a gravitationally bound system, such as a cluster of galaxies. Put another way, measuring the velocities of the components of the gravitationally bound association, and hence of the centripetal forces present, provides a gauge of how much mass—often called the gravitational mass—is present.

Beginning in the 1930s, a number of astronomers noted that the visible mass (that is, the mass thermally radiating in the visible portion of the electromagnetic spectrum) was a good deal less than the gravitational mass—by a factor of 10. It seemed that at least 90 percent of the mass in galaxies was not visible. What form could this "cold, dark matter" take? Hence, the title of this book.

Some of the mystery was solved when radio astronomers found that substantial amounts of mass were hidden in hydrogen clouds, but it seemed this might not be the whole story. At the same time, developments in particle physics suggested that the answer could lie in the physics of the Big Bang. Some insights gained from the zoo of particles that were being discovered or proposed implied that exotic forms of elementary particles could provide the missing mass—and also put the universe into a remarkable balance, with the amount of kinetic energy available in its expansion exactly balancing the gravitational binding energy. The universe, then, would never collapse upon itself, nor would it expand without limit.

Meanwhile, it appears that the Big Bang could be the mother of all particle accelerators, and cosmological observations could provide the final clues necessary to resolve the fundamental nature of things.

The author describes all this and much more in a highly entertaining and insightful way. She organizes the material so that a number of thematic developments are presented in parallel. The book begins by forging a link between the philosophical underpinnings of Western science and today's deepest scientific problems. It then reviews some of the outstanding developments in astronomy with the current ones in physics and chemistry. In so doing, Bartusiak establishes the many links that emerged between the different physical sciences and how our picture of the universe developed. The presentation is not always chronological, but focuses more on the themes of "light" and "dark"—direct and indirect sources of information about the cosmos. This mode of presentation is quite effective, and I am now tempted to use it in some of my courses.

Regarding contemporary developments, Bartusiak has meticulously interviewed many astronomers and culled historical archives to assess the contributions of past generations. Knowing some of the individuals she has interviewed, I was impressed by her ability to capture their personalities and show how those personalities shaped their viewpoints. By skillfully weaving together these different threads, she has done a superb job of explaining the current views and questions that lie before us.

A couple of themes deserve special mention. One is the interplay between theory, experiment, and observation. Astronomy has undergone a revolution with the development of detectors that peer into the heavens at all wavelengths in the electromagnetic spectrum. The contemporary astronomer does not necessarily spend long nights at an observatory, and is more likely to obtain digitized data from a charge-coupled device (CCD) that has undergone substantial filtering and signal processing to enhance the underlying signals.

Further, mathematics and its role in modern physics, the nature of different forms of symmetry as well as geometry, now have a profound role in astrophysics. The abstract particles predicted from mathematical and geometrical considerations—but not necessarily observed—may hold the key to our understanding of the missing mass problem and the major constituents of the universe.

Another theme is the role of women in astronomy. As an observational science, astronomy requires meticulous, laborious observations and statistical analysis. Many of the misconceptions of the 19th century were put to rest by large numbers of women known as "computers," who worked at Harvard University after the turn of this century, analyzing spectroscopic images of the stars. They were hired largely because they worked for very low wages (roughly a fourth of a male's pay) and were exceedingly careful about their work. Relying on data, they were largely responsible for shaping our view of the size, composition, and evolution of stars—particularly through the contributions of a few extraordinarily talented women who were among them. Ironically, only today are women able to assume leadership roles in this discipline.

I have two minor complaints. First, there are no color plates in this book—instead, black-and-white photographs are printed on newsprint-quality paper. The case presented

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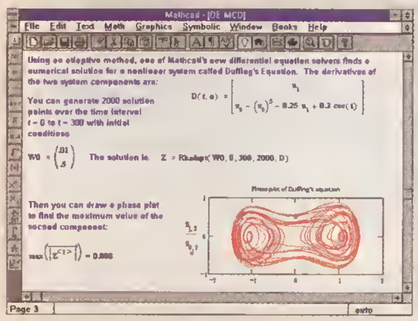

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Books

(Continued from p. 12)

for the importance of subtle special variations is quickly lost; one figure depicting possible gravitational lensing (a relativistic effect that provides a hint as to the location of some of the missing mass) could be titled "black on black."

Second, while the book starts out with a bang (albeit not the big one), it ends with a whimper. Although there is no guarantee of it, the present era could be the most eventful one in science. New instruments and detectors coming on-line could further revolutionize the science and add to our understanding of the cosmos. I would have preferred to see the book end on a more upbeat note. We are living at a particularly exciting time, a time when we may finally and unequivocally be able to answer many of the questions posed by philosophers through the ages about the nature of the universe. This is a superb book, nevertheless, and I recommend it highly.

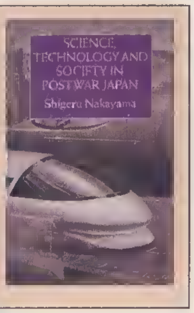
William I. Newman (M) is professor of planetary physics, astronomy, and mathematics at the University of California, Los Angeles. Formerly, he was a member of the Institute for Advanced Study in Princeton, a Guggenheim Foundation Fellow in astrophysics at Cornell University, and a Stanislaw Ulam visiting scholar in nonlinear studies at Los Alamos National Laboratory. His research interests include dynamical problems in theoretical astrophysics and geophysics, and problems in signal processing and information theory.

R&D and society in postwar Japan

Fumio Kodama

This book attempts a critical analysis of the mechanisms by which Japan has promoted the development of its science and technology since World War II. It also tries to assess the impact of those developments on Japanese society and vice versa.

Science, Technology and Society in Postwar Japan.
Nakayama, Shigeru, Kegan Paul International, London (distributed by Routledge in New York), 1992, 256 pp., US $89.95.



In highlighting the special features of the country's postwar scientific performance, the author avoids the usual distinctions between science and technology and the basic and applied sciences. His approach to Japan's activities in these fields is therefore unlike the traditional perspective of several earlier documents in English, mainly the products of government-related institutions. In departing from their framework, he is successful in pointing out several new perspectives and insights.

To be more specific, he argues that the crucial factors differentiating the several types of scientific endeavor can be found in the social and sociological mechanisms by which each is assessed and utilized. For this reason, he adopts a four-sector approach: academic, public, private, and citizen.

Employing this device, he creates the following unconventional wordings: "publicly sponsored science," set up by bureaucrats who appraise its output; "privately sponsored science," practiced in the private sector and appraised by private enterprises in order to increase profits; "technocratic science," which has been guided by the Ministry of International Trade and Industry within the framework of a "bureaucratic industrial complex"; and "service science," which is directly assessed by citizens. Some of these descriptions may provoke the curiosity of readers, but not all of them evoke new perspectives.

Nakayama offers these timeframes of Japanese postwar history: occupation and recovery, in the late 1940s to early '50s; high growth, in the late '50s to early '60s; reflection and restructuring, in the late '60s and the '70s; and the nationalism and internationalism of the '80s. I was especially impressed with his chapters on democracy versus technocracy in science (in the occupation and recovery period); changing models of Japanese universities (in the occupation and high-growth period); and grassroots revolt–possibility of service science (in the reflection period).

Those chapters I found less persuasive because their descriptions are a little too parochial deal with high economic growth and private science, and with the microelectronics revolution. The three chapters on the expansion and limits of academic science, weakness of national projects, and competition and cooperation–Japan-USA phase left me feeling neutral because they include new arguments but are not supported by valid empirical evidence

What is lacking in this book, its missing link, is that the author does not explain how the four sectors are interdependent and interrelated. In his introductory chapter, Nakayama writes that he has attempted to describe the dynamics of the relationship among these four social sectors' interests, using the nature and characteristics of a nation's science and technology to determine the nature of the equilibrium maintained among these sectors. This is a difficult goal to reach.

The author admits that most of the book derives from his own personal observations and interpretations. His arguments are based not so much on careful documentation of the period as on his impressions and reminiscences of the time he has lived through (he received a Ph.D. in the history of science from Harvard almost 30 years ago). In other words, he applies few analytic tools to an empirical database.

Given Nakayama's background, it is understandable that he devoted more of the book to academic and public science than to private science and industrial technology. Even so, in view of the fact that more than 80 percent of Japanese R&D is funded by private industry, the description of private science is too short and not deep enough: only one category is presented.

Indeed, his analytic framework—his four-sector approach—might not be powerful enough to comprehend the full picture of Japanese science and technology. Certainly the emergence of high technology necessitates a more detailed classification, one that should have covered much more than private science and the microelectronics revolution.

Fumio Kodama is professor of innovation policy at Saitama University's Graduate School of Policy Science. In 1991–93, he was visiting professor at Harvard University's Kennedy School of Government and at Stanford University's mechanical engineering school. He is the author of Analyzing Japanese High Technology *(Pinter, London, 1991). Its Japanese edition won the 1991 Yoshino Prize. Next spring, the second, revised edition will be published by Harvard Business School Press. He is a member of the board of directors of the Engineering Academy of Japan.*

EDITOR: Glenn Zorpette

Recent Books

Structured Approach. *Barzel, Ronen*, Academic Press, San Diego, Calif., 1992, 334 pp., $39.95.

High-Power GaAs FET Amplifiers. Ed. *Walker, John L.B.*, Artech House, Norwood, Mass., 1993, 369 pp., $89.

Scientific Computing: An Introduction with Parallel Computing. *Golub, Gene*, and *Ortega, James M.*, Academic Press, San Diego, Calif., 1993, 442 pp., $49.95.

The 80X86 IBM PC & Compatible Computers, Vol. 1: Assembly Language Programming on the IBM PC, PS and Compatibles. *Mazidi, Muhammad Ali*, and *Mazidi, Janice Gillispie*, Regents/Prentice Hall, Englewood Cliffs, N.J., 1993, 329 pp., $46.67.

AERIALS II. *Sterba, Kurt N.*, and *Paddle, Lil*, Worldradio Books, Sacramento, Calif., 1993, 77 pp., $11.

Intelligent Database Tools & Applications: Hyperinformation Access, Data Quality, Visualization, Automatic Discovery. *Parsaye, Kamran*, and *Chignell, Mark*, John Wiley & Sons, New York, 1993, 543 pp., $34.95.

Recent books

(Continued from p. 14)

Radar Cross Section, 2nd edition. *Knott, Eugene F., et al.*, Artech House, Norwood, Mass., 1993, 611 pp., $85.

Cockpit Resource Management. Eds. *Wiener, Earl L., et al.*, Academic Press, New York, 1993, 519 pp., $75.

Applications Programming in ANSI C, 2nd edition. *Johnsonbaugh, Richard*, and *Kalin, Martin*, Macmillan Publishing, New York, 1993, 683 pp., $42.

Using the ORACLE Toolset. *Krohn, Mike*, Addison-Wesley, New York, 1993, 327 pp., $30.95.

Radiowave Propagation Over Ground. *Maclean, T.S.M.*, and *Wu, Z.*, Chapman & Hall, New York, 1993, 299 pp., $95.

Flexible and Distance Learning. *Van den Brande, Lieve*, John Wiley & Sons, New York, 1993, 263 pp., $195.

Vest Pocket Guide to the National Electrical Code, 1993 edition. *Fischer, Marvin J.*, Prentice Hall, Englewood Cliffs, N.J., 1993, 284 pp., $14.95.

The 8085A Microprocessor: Software, Programming & Architecture, 2nd edition. *Brey, Barry B.*, Regents/Prentice Hall, Englewood Cliffs, N.J., 1993, 426 pp., $58.67.

Open Systems Interconnection: Its Architecture and Protocols, revised edition. *Jain, Bijendra N.*, and *Agrawala, Ashok K.*, McGraw-Hill, New York, 1993, 586 pp., $50.

Engineering Analysis of Flight Vehicles. *Ashley, Holt*, Dover Publications, New York, 1992, 400 pp., $12.95.

The Basics of Soldering. *Rahn, Armin*, John Wiley & Sons, New York, 1993, 369 pp., $59.95.

Electrical Machines and Drives: A Space-Vector Theory Approach. *Vas, Peter*, Oxford University Press, New York, 1992, 808 pp., $165.

MOS ICs: From Basics to ASICs. *Veendrick, H.J.M.*, VCH, New York, 1992, 430 pp., $43.

Enterprise Database Connectivity: The Key to Enterprise Applications on the Desktop. *Hackathorn, Richard D.*, John Wiley & Sons, New York, 1993, 326 pp., $39.95.

Fuzzy Measure Theory. *Wang, Zhenyuan*, and *Klir, George J.*, Plenum Publishing, New York, 1992, 354 pp., $69.

Voice Processing. *Pelton, Gordon E.*, McGraw-Hill, New York, 1993, 396 pp., $45.

The Elements of Fiber Optics. *Meardon, S.L. Wymer*, Regents/Prentice Hall, Englewood Cliffs, N.J., 1993, 238 pp., $35.33.

Ferroelectric Crystals. *Jona, Franco*, and *Shirane G.*, Dover Publications, New York, 1993, 398 pp., $12.95.

ORACLE 7: The Complete Reference. *Koch, George*, and *Muller, Robert*, Osborne/McGraw-Hill, New York, 1993, 1000 pp., $34.95.

OSI Upper Layer Standards and Practices. *Hebrawi, Baha*, McGraw-Hill, New York, 1993, 428 pp., $45.

Practical XView Programming. *Bibb, Kenneth W.*, and *Wake, Larry*, John Wiley & Sons, New York, 1993, 460 pp., $34.95.

Distributed Computing: A Practical Synthesis. *Umar, Amjad*, PTR/Prentice Hall, Englewood Cliffs, N.J., 1993, 736 pp., $59.

Vital Signs: Using Quality, Time, and Cost

Recent books

Performance Measurements to Chart Your Company's Future. *Hronec, Steven M.*, and *Arthur Anderson & Co.*, Amacom, New York, 1993, 247 pp., $27.95.

McGraw-Hill's National Electrical Code Handbook, 21st edition. *McPartland, Joseph F.*, and *McPartland, Brian J.*, McGraw-Hill, New York, 1993, 1294 pp., $54.50.

The GUI Guide: International Terminology for the Windows Interface, European edition. *Microsoft Corp.*, Microsoft Press, Redmond, Wash., 1993, 256 pp., $29.95.

Meteor Burst Communications: Theory and Practice. Ed. *Schilling, Donald L.*, John Wiley & Sons, New York, 1993, 459 pp., $84.95.

FoxPro 2.5 for DOS Made Easy. *Jones, Edward*, Osborne/McGraw-Hill, New York, 1993, 700 pp., $24.95.

Peer-to-Peer LANs Networking Two to Ten PCs: A Guide to Selecting, Installing, and Managing Low-Cost LANs. *Madron, Thomas W.*, John Wiley & Sons, New York, 1993, 292 pp., $26.95.

Things That Make Us Smart: Defending Human Attributes in the Age of the Machine. *Norman, Donald A.*, Addison-Wesley, New York, 1993, 304 pp., $22.95.

Running MS-DOS: Covers Through Version 6.0, 6th edition. *Wolverton, Van*, Microsoft Press, Redmond, Wash., 1993, 640 pp., $24.95.

The Physics of Micro/Nano-Fabrication. *Brodie, Ivor*, and *Muray, Julius J.*, Plenum Publishing , New York, 1992, 650 pp., $95.

Microsoft Guide to Visual Basic for MS-DOS: The Complete Guide to Visual Basic Programming. *Aitken, Peter G.*, Microsoft Press, Redmond, Wash., 1993, 496 pp., $24.95.

The J. Ranade UNIX Primer. *Ranade, Jay*, and *Zamir, Saba*, McGraw-Hill, New York, 1993, 650 pp., $45 (hardcover), $29.95 (paperback).

The Handbook of Intelligent Control: Neural, Fuzzy, and Adaptive Approaches. Eds. *White, David A.*, and *Sofge, Donald A.*, Van Nostrand Reinhold, New York, 1992, 568 pp., $59.95.

Solid-State Power Conversion Handbook. *Tarter, Ralph E.*, John Wiley & Sons, New York, 1993, 719 pp., $89.95.

Intel's SL Architecture: Designing Portable Applications. *Yuen, Desmond*, McGraw-Hill, New York, 1993, 331 pp., $39.95.

The Microsoft Guide to Managing Memory with MS-DOS 6: Installing, Configuring, and Optimizing Memory for MS-DOS and Windows Operating Systems, 2nd edition. *Gookin, Dan*, Microsoft Press, Redmond, Wash., 1993, 224 pp., $14.95.

The Joy of X: An Overview of the X Window System. *Mansfield, Niall*, Addison-Wesley, Reading, Mass., 1993, 368 pp., $22.75.

Cooperative Processing Using CICS. *Lamb, Rob K.*, McGraw-Hill, New York, 1993, 283 pp., $45.

Visions of the Future: Art, Technology and Computing in the Twenty-First Century. *Pickover, Clifford A.*, St. Martin's Press, New York, 1992, 212 pp., $29.95.

Magnetics Engineering Fundamentals and Computer-Aided Design Solutions. *Lilienstein, Fred M.*, Van Nostrand Reinhold, New York, 1993, 432 pp., $99.95.

Microcomputer Systems: Architecture and Programming. *Byrd, Joseph S.*, and *Pettus, Robert O.*, Prentice Hall, Englewood Cliffs, N.J., 1993, 448 pp., $59.

Graphics Programming Solutions. *Sanchez, Julio*, and *Canton, Maria P.*, McGraw-Hill, New York, 1993, 500 pp., $60 (hardcover), $42.95 (paperback).

Design of Electronic Circuits and Computer Aided Design. *Shah, M.M.*, John Wiley & Sons, New York, 1993, 234 pp., $34.95.

Applications and Design with Analog Integrated Circuits, 2nd edition. *Jacob, J. Michael*, Prentice Hall, Englewood Cliffs, N.J., 1993, 575 pp., $58.67.

Power Mosfet Design. *Taylor, B.E.*, John Wiley & Sons, New York, 1993, 198 pp., $41.50.

High-Speed Digital Design: A Handbook of Black Magic. *Johnson, Howard W.*, and *Graham, Martin*, Prentice Hall, Englewood Cliffs, N.J., 1993, 447 pp., $46.

Propagation, Scattering and Dissipation of Electromagnetic Waves. *Ilyinsky, A.S., et al.*, Peter Peregrinus/IEE, Piscataway, N.J., 1993, 277 pp., $99.

Future Trends in Telecommunications. *Horrocks, R.J.*, and *Scarr, R.W.A.*, John Wiley & Sons, New York, 1993, 452 pp., $69.95.

Globalization, Technology, and Competition: The Fusion of Computers and Telecommunications in the 1990s. Eds. *Bradley, Stephen P., et al.*, Harvard Business School Press, Boston, 1993, 392 pp., $34.95.

(Continued on p. 50B)

Washington watch

White House appoints high-tech advisory boards

The Clinton administration's emphasis on science and technology gained momentum in late November when the President created two advisory boards, including one with cabinet status.

The cabinet-level group is called the National Science and Technology Council; its members include the heads of Federal departments overseeing commerce, defense, energy, the environment, health, and space. The other advisory group draws its members from the private sector and is named the President's Committee of Advisors on Science and Technology.

The new council's principal purpose will be to "establish clear national goals" for the U.S. government's investments in science, space, and technology. The council, whose head is yet to be selected, will coordinate R&D budgets so that they focus not on agency missions but on national goals in areas like information technology, health, and transportation. The ultimate goal, Clinton said in November, is to improve the quality of life and the nation's long-term economic strength. The council replaces previous groups like the National Space Council, the National Critical Materials Council, and the various committees of the Federal Coordinating Council for Science, Engineering, and Technology.

The President's Committee of Advisors on Science and Technology is to comprise at most 15 executives from industry, education, and research institutes. They will advise the President and the new council under the joint chairmanship of John H. Gibbons, the President's science and technology advisor, and a representative of the private sector.

More conversion money

The government's infusion of cash to aid the shrinking defense industry continued with two more rounds of grants under the Technology Reinvestment Program (TRP).

The emphasis is on dual-use technologies for both commercial and military applications. Some $464 million was available for fiscal 1993, and more than 1200 organizations have received grants so far. U.S. government funds must be at least matched by the grantees.

The awards include regional and local outreach programs, education and retraining initiatives, and new technology development.

Among the retraining projects is one by four Massachusetts universities to help defense engineers become quickly proficient in biotechnology and biomedicine. Southern California universities are starting a similar program on microfabrication technology. Other program topics include advanced transportation, manufacturing, and photonics.

In the technology category was a $5.1 million effort by Boeing, Honeywell, Carnegie Mellon University, and Virtual Vision of Redmond, Wash., to create a portable, head-mounted display that will allow hands-free presentation of information for manufacturing, assembly, maintenance and training.

In other efforts, Rockwell International is leading a team of companies from California and Texas to develop a $15.1 million

Washington watch

trauma care information management system to help monitor and diagnose patients remotely. And Westinghouse and Chrysler are developing an electric vehicle powertrain with $25 million from the TRP.

The IEEE was among the awardees of a team led by the American National Standards Institute to develop a $4.9 million electronic network to speed the development and distribution of technical standards.

The TRP is implemented by six Federal agencies: Defense, Commerce, Energy, Transportation, the National Aeronautics and Space Administration, and the National Science Foundation. For more information, call 1-800-Dual-Use. For copies of the awardees, call 703-697-5737.

Better Baldrige criteria

Though the criteria for the Malcolm Baldrige National Quality Award have never appeared on *The New York Times* best-seller list, more than a million copies are in use as guidelines worldwide, according to the National Institute of Standards and Technology (NIST), in Gaithersburg, Md.

Now the criteria have been expanded and clarified and in addition stress the integration of the operational aspects of quality with business planning. Copies of the 1994 award criteria, along with application forms, may be obtained from NIST by calling 301-975-2036. Multiple copies in packets of 10 can be ordered for $29.95 plus postage from the American Society for Quality Control at 800-248-1946. The order number is T998.

Clinton progress report

Nine months after issuing some general goals for technology policy initiatives on Feb. 22, the Clinton administration recently assessed its progress. No grades were given, but the list of endeavors in the "Technology for Economic Growth: President's Progress Report" runs to 68 pages.

Among the accomplishments cited are shifting Federal R&D priorities to civilian technology; forging industry partnerships in electronics, autos, energy, and environment; developing an export strategy that will free up $35 billion in high-tech exports; and planning a national information infrastructure and transferring 200 MHz of spectrum to the private sector for wireless services.

Just the fact that a President is so concerned about technology is a big change from past Administrations. In a cover letter, Clinton calls technology policy "a key element of my economic strategy" and asks for new cooperation among government, industry, labor, and academia. For more information, call the White House at 202-456-7150.

President endorses Engineers Week

President Bill Clinton sent a National Engineers Weeks message in early December reminding the public of "the integral role that engineers play in shaping [the] future."

The President cited engineers' contributions to areas as diverse as disaster relief and health care. He also encouraged the profession to "continue to fulfill its primary mission of 'Turning Ideas Into Reality' if America is to maintain a leading role among nations."

National Engineers Week will be celebrated Feb. 20–26. Communicating through educational programs, awards and recognitions, community service, and media campaigns, engineers inform society on how their contributions have upgraded everyone's standard of living. The 1994 event is led by the American Society of Civil Engineers and Rockwell International Corp.

National Engineers Week was founded in 1951 by the National Society of Professional Engineers, and now receives the backing of an array of engineering societies, including the IEEE, industrial corporations, and U.S. government agencies.

John A. Adam Washington Editor

Technically speaking

The pocket computer's many aliases

Kevin Self

Like all new technologies, the emerging portable computer market is spawning its own jargon. Dataquest Inc., the market research firm in San Jose, Calif., predicts that by 1995 every other personal computer sold (and maybe more) will be portable. The industry is already at work remodeling words to suit its purposes.

For instance, many of the new machines are so small that they trade in a keyboard for a pen-based or touch tablet. This change presents new openings for errors, pointed out Greg Stikeleather, president and chief executive officer of Aha! Software Corp., Mountain View, Calif. The familiar typographic mistake, or typo, can no longer occur on a machine that doesn't support typing. Accordingly, he has noticed the term *write-o,* used to describe a mistake in handwriting or character recognition made while entering data into a pen-based machine. In many cases, a note or memo can be stored as an image, rather than being interpreted as handwriting. Aha! Software has developed software that can treat writing as an editable digital image, reducing the amount of processing needed by the computer. This technology has been nicknamed *digital ink,* because the data is no longer treated as straight penmanship.

Worse yet, consistent nomenclature for these miniature marvels remains elusive. While *palmtop* and *picocomputer* have been suggested, the industry has yet to reach a consensus. When John Sculley, former chief executive officer of Apple Computer Inc., Cupertino, Calif., announced the Newton computer in January 1992, he dubbed it a *personal digital assistant.* Compaq Computer Corp., Houston, Texas, has announced plans for a *mobile companion*. Still other manufacturers use names such as *pentops, electronic organizers, personal intelligent communicators,* or *pocket digital assistants.*

Even their users need a new name, it seems. At any rate, BIS Strategic Decisions, of Norwell, Mass., has undertaken to classify this subspecies of computing consumer. Its market survey, *The Mobile Professional Market Segmentation,* found that nearly three out of every four members of today's professional workforce is mobile. To better understand how to market to these wandering workers, BIS Strategic categorized them by their work habits.

Globe-trotters are the largest segment of the portable computer market. In the main, they are older males who often travel abroad. *Road Warriors* spend nearly a third of their time away from the office, often in meetings at their clients' locations. *Collaborators* are well-educated young professionals who spend 85 percent of their time working with others, but require the quick access to information that portable computers give. *Corridor Cruisers* work with others in the same building, but are rarely in their own office. And *Hermits* also spend a lot of time away from their desks but work alone.

WerdWatch

Technically Speaking hit a nerve last October, when we suggested a Worldwide Engineering Reputation Defense Society (Werds) be formed to protect the good name of engineers. Apparently, besides being technically skilled, engineers are a proud lot with a sense of humor. We were deluged with mail agreeing that our noble profession has been much maligned. Our engineering readership, problem-solvers by nature, immediately proposed ways in which the profession could beef up its reputation.

Peter Hissen of Antwerp, Belgium, suggested television shows could be produced to improve our image, including "L.A. Engineers," "The Mold and the Beautiful" (about polymer engineering), and even The E-Team. This column's editor commented recently on National Public Radio's "Marketplace" show in the United States that distributing bubble gum trading cards with pictures of famous engineers could promote a positive image among children. However, Daniel Claassen of the United Kingdom reports engineering discrimination in academic media. In an Oxford University student newspaper, he caught the slander: "Show me an engineer and I show you a bore; show me two, and I run away."

Some readers wanted to take the society one step further. Fred Mapplebeck, Paul Wildes, David Darnden, and Fran Hancheck all suggested that local Werds chapters could be formed, addressing particular needs on a country-by-country basis. The resulting National Engineering Reputation Defense Society (or Nerds) would have interesting stationery, to say the least. At rallies we could carry banners proclaiming, "We're the NERDS, and we're proud!" Readers are encouraged to make their own Nerds buttons and T-shirts and wear them in public.

The irony in the name Nerds is not easy for Technically Speaking to pass up. It was actually our first choice, but after some consideration we decided that using the word "national " would be doing a disservice to the global nature of the IEEE. Reader response has convinced us, however, that in the future we shouldn't try quite so hard to check our tongues-in-cheek.

Pointing a finger

Houston Chronicle columnist Thom Marshall recently commented on the pros and cons of technology's effect on education. In his article "High-tech era has drawbacks," he astutely noted that "Without education, it is obvious we wouldn't have all the digitized, computerized, time-saving electronic devices that surround us, here in our high-tech era." Little did Marshall realize, however, that when he used the adjective *digitized* to modify devices, he crossed over from scholarship into science fiction.

The second edition of the Random House Dictionary of the English Language defines the verb *digitize* as to "convert [data] to a digital form for use in a computer." Digitizing can be done with any signal or information, most commonly with text or illustrations. Converting an electronic device or any matter to a digital form, however, would take a device roughly equivalent to the transporter used in the Star Trek television show. A better choice would have been *digital,* meaning "of, pertaining to, or using data in the form of numerical digits."

When contacted for clarification, Marshall acknowledged his error. "Guilty as charged," he told Techncially Speaking. "I was looking for a word to rhyme with computerized, and digitized fit the bill." Marshal did point out that if one used the "finger" interpretation of *digit,* his wording could be correct. He was vindicated by a reference in the *Oxford English Dictionary* to a "very rare" usage of *digitize* to mean "manipulate or treat in some way with the fingers." This could start a disturbing advertising trend: every product that has ever been handled could be labeled *digitized. Caveat emptor;* let the buyer beware!

Technically Speaking is intended as a commentary on the use and misuse of technical language and culture, both within the scientific/engineering community and by the general public. Comments, concerns, commendations, and condemnations will be accepted, often cheerfully. Readers are invited to reply by mail, care of Technically Speaking at IEEE Spectrum, *or by e-mail to Klself@mcimail.com. Please indicate the city, state, and country you are writing from, as well as IEEE affiliation, if any.*

Contributing Editor Kevin Self (M) surveys the etymological world from his workbench at Dallas Semiconductor Corp., in Dallas.

CONSULTANT: Anne Eisenberg, Polytechnic University.

Software reviews

Effortless dynamic system analysis

Mark S. Mirotznik

SystemView. *Elanix Inc. The program requires an Intel 80386 or 80486 computer with 4-MB RAM minimum, about 3 MB of hard disk, and Microsoft Windows version 3.0 or later. Purchase price for basic package is US $985 with additional libraries available. A student version will soon be available for $150.*

SystemView is a powerful package for simulating and analyzing dynamic systems on 386- and 486-based PCs. Developed by Elanix, SystemView has made good use of the Microsoft Windows environment and a well-polished graphical interface to raise dynamic system simulation to a new level of user-friendliness.

Programs of this kind allow engineers to model a wide range of dynamic systems in areas ranging from digital communication to robotic control. The user simply defines the system layout, including input sources and timing information, and instructs the program to simulate the output response. Several features make SystemView stand out from the crowd. Besides the friendly interface, they include a large variety of functions and a reasonable price.

SystemView's chief selling point is its well-thought-out graphical interface. I found the program intuitively simple and even fun to work with. Several of my undergraduate students tested it in their communications course and without a manual were simulating a complicated spread-spectrum technique in less than 15 minutes.

Complicated systems are easily defined by using the mouse to grab operator and function icons (called tokens) from a well-stocked library. The tokens are then linked graphically to construct the desired system. Small systems may be grouped together into a single icon (MetaSystem) and used in larger systems. SystemView does, however, limit the number of tokens to 512, which might be too few for very large system simulations.

The package's built-in library of tokens includes sources, mathematical operations, functions, and analysis features. Some of the most impressive include: a linear system token that can be used to design both infinite-duration impulse-response (IIR) and finite-duration impulse-response (FIR) digital filters, and assorted modulation tokens.

Installation is automatic, and the manual is well written. For this review, I tried SystemView on a 50-MHz, 486-based PC with 8 MB of RAM running Microsoft Windows version 3.1. The program ran very smoothly with no application errors (a pleasant surprise for a new Windows product). *Contact: Elanix Inc., 5655 Lindero Canyon Rd., Suite 304, Westlake Village, CA 91362; 818-597-1414; 1-800-535-2649 (U.S.); or* **circle 110.**

Mark S. Mirotznik is an assistant professor in the department of electrical engineering, The Catholic University of America. E-mail address is mirotz@pluto.ee.cua.edu.

A handy tool for data-driven problems

John R. Hines

BBN/Cornerstone. *Interactive software for data analysis and visualization. The current version runs on Hewlett-Packard 700 and Sun 4 workstations under HP/UX and Sun/OS, respectively. The price of licenses is a function of workstation CPU power: single-user, single-workstation licenses start at US $1795, single-user, multiple-workstation licenses start at $2395.*

BBN Software Products markets BBN/Cornerstone as an easy-to-use but powerful tool for solving data-driven problems. My evaluation confirms that it is both powerful and easy to use. (In fact, it is too powerful and too easy to use. This review was delivered two months later than promised because others working at the MicroSwitch Division of Honeywell Inc. demanded time to use Cornerstone to analyze data for critical projects. Most novices could perform the analyses they needed after a 15-minute tutorial by an experienced user.)

The key to Cornerstone is its click-and-point WIMP user interface, which is much like the interface on a Macintosh or a PC using Windows. (WIMP stands for windows/icons/mouse/pull-down menus.) On the Hewlett-Packard 715/50 I used during this review, the interface is tightly linked to HP's HP-Vue (a WIMP window manager that runs on top of HP/UX); so I had no problem starting the package up and running it even though I am not a Unix power user.

Users have two tools for editing and querying datasets. With a graphical dataset editor, they can easily manipulate data stored in tables, even if the table is in a database format. Users may also edit or query datasets from graphical displays of data.

During each session, Cornerstone generates a Workmap that logs the steps performed during the data analysis. Each work map is displayed graphically for manipulation by the point-and-click interface. The user may run a complete analysis from the beginning or from a later point by clicking on the appropriate node of the display.

If the user has data stored on a TCP/IP-based network, Cornerstone will exploit the capabilities of the network, extracting data from relational and Structured Query Language (SQL) database servers. Cornerstone's Data Navigator uses the point-and-click interface to link pieces of data scattered across the network for an analysis.

As Cornerstone does not differ much from comparably priced data analysis packages at the nuts-and-bolts level, I have focused on usability rather than features. However, BBN Software Products does offer a number of optional modules having capabilities unavailable elsewhere. Anyone doing serious statistical data analysis should buy the optional multiple regression, multivariate analysis, and principal component analysis modules.

This is a great tool, but it still needs work. Users who want to write customized applications have to use the vendor's Cornerstone Extension Language, a visual programming language based on C++. The optional modules need enhancing. In particular, the one for principal components analysis lacks some modern techniques—for example, rotating to simple structures.

My biggest reservation about Cornerstone is that it runs only in a Unix environment. However, the vendor informs me that a Windows version is expected soon. This would simplify the access of data on PC-based networks, which is cumbersome with the present Unix version. *Contact: BBN Software Products, 150 Cambridge Park Dr., Cambridge, MA 02140, 617-873-5000; or* **circle 111.**

John R. Hines (A) is silicon sensors engineer at Honeywell Inc.'s Microswitch Division, Richardson, Texas.

Recent software

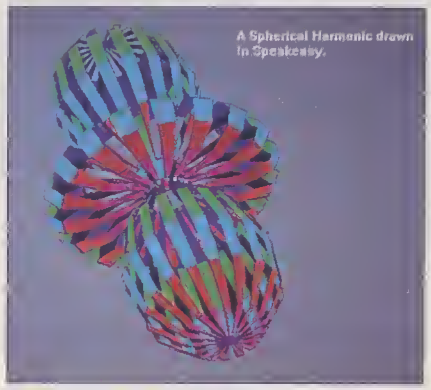
M + + Release 5. A math library and multidimensional array language extension to C++, for DOS/Windows (US $395 and up), Windows NT, OS/2 ($595 and up), Unix workstations ($795 and up). *Contact: Dyad Software Corp., 6947 Coal Creek Parkway SE, Suite 361, Renton, WA 98059-3151; 800-366-1573 (United States); 206-637-9426; fax, 206-637-9428; or* **circle 112.**

EEs' tools & toys

Mainframe workhorse now runs on DOS machines

The Speakeasy math package has been solving complex scientific and financial problems on mainframe computers for almost three decades. Now Speakeasy Computing Corp. has made the software available for IBM-type personal computers. The tool's capabilities include array and matrix algebra, econometric modeling, statistics, linear and quadratic programming, differential equations, and interactive graphics.

A 32-bit application, Speakeasy takes full advantage of extended memory on 386 and 486 machines. According to company president Stan Cohen, it exploits the architectures of those microprocessors "to tackle problems that have previously been beyond the reach of most desktop-based mathematical systems."



PC Speakeasy's analysis environment has presentation-quality interactive graphics.

But, given the power of competitive math packages, Cohen feels that Speakeasy's strongest advantage is its extremely friendly user interface. Instead of easily forgotten abbreviations, the program's built-in procedure language uses such familiar words as ARRAY, BESSEL, and COS. Should a user forget any of the commands, an extensive help facility is always to hand.

Menus are available for new users and for performing basic housekeeping functions, such as the storage and retrieval of data and procedures. For most interactive problem-solving, however, typing commands is a more natural and efficient way to work. So Speakeasy employs both approaches. The package also permits users to add their own custom menus.

Interactive graphics are an integral part of the Speakeasy environment, which includes a variety of pre-programmed chart types, including continuous-line, bar, and pie charts. Three-dimensional projections with hidden-line removal, contour plots, and many graphical forms are also provided.

PC Speakeasy requires a 386 or better PC with a math coprocessor and at least 6 MB of RAM (8 MB recommended). It requires 10 MB of disk space and will run under DOS 3.1 or higher. A mouse is highly recommended, but not required.

The program sells for US $995, including 90 days of free telephone support. *Contact: Speakeasy Computing Corp., 224 S. Michigan Ave., Chicago, IL 60604; 312-427-2400; fax, 312-427-4777; or* **circle 100.**

SOFTWARE

Books, on line and off

O'Reilly & Associates Inc., the folks who brought you *The Whole Internet User's Guide & Catalog*, has put out its first issue of *ora.com*. It's a combination catalog, magazine, and introduction to the publishing company, which specializes in books on Unix, X Windows, and related topics.

Its latest wrinkle is an on-line information resource on the company's books and how to download code examples and place orders. It also has a Unix bibliography with information on current books by subject area. Details on accessing the on-line resource are included in *ora.com*.

The magazine/catalog is offered free of charge. *Contact: O'Reilly & Associates Inc., 103 Morris St., Suite A, Sebastopol, CA 95472; 707-829-0515; toll-free, 800-998-9938; fax, 707-829-0104; e-mail, letters@ora.com; or* **circle 101.**

Fourier transforms for a low price

For only $59, a software package developed by Integrated Scientific Resources and distributed by DH Systems Inc. will add fast Fourier transform (FFT) capability to Lotus 1-2-3 and greatly enhance the FFT capability of Microsoft Excel. The add-in program is a dynamic link library that is integrated into the spreadsheet environment.

FFTtools will calculate forward and reverse transforms for data sets with up to 8192 points, and offers a choice of six windowing functions—Blackman, Hamming, Hanning, Parzen, tapered rectangular, and triangular taper. It is extremely easy to use: the user just selects the data, its output locations, and analysis options, and in a second or two the results are displayed. Execution speed depends on many factors, including data size and computer hardware. A 1024-point FFT takes under a second on a 486-based machine with a 33-MHz clock (486DX/33).

A similar program, FFTpro, is available for adding Fourier analysis to programs written in C, Basic, or Pascal. It sells for $169. For both products, printed documentation costs $25 extra. *Contact: DH Systems Inc., 1940 Cotner Ave., Los Angeles, CA 90025; 310-479-447; toll-free, 800-747-4755; fax, 310-478-4770; or* **circle 102.**

EDUCATION

Internetworking alphabet soup

Navigating over an internet (a collection of interconnected networks of similar or dissimilar types) is tough enough for experts who know all of the relevant terminology. For those of us who thought that PVC meant polyvinyl chloride instead of permanent virtual channel, it can be a nightmare.

What we need, of course, is a pocket-sized, 50-page booklet entitled *A Hitchhiker's Guide To Internetworking Terms And Acronyms*—something that covers technologies that have been around for a while, like Ethernet and Token Ring, and also spells out less familiar items from the world of ATM, Fibre Channel, and Sonet.

Fortunately, just such a booklet is available free of charge from Interphase Corp. Lest anyone get the wrong idea, the guide does more than just spell out acronyms. Its ATM entry, for example, explains that asynchronous transfer mode is a low-delay, high-bandwidth multiplexing and packet-switching technique based on fixed-length 53-byte packets. *Contact: Interphase Corp., 13800 Senlac, Dallas, TX 75234-8823; 214-919-9111; or* **circle 103.**

Learning technical Japanese

To help U.S. engineers compete with their Japanese counterparts on a more nearly equal basis, the Massachusetts Institute of Technology has developed a pair of courses in technical Japanese—one for computer scientists and electrical engineers, and the other for materials scientists and specialists in related fields, such as physics and chemical and mechanical engineering.

The courses are intended to give non-Japanese students the ability to read technical documents in the Japanese language. At present, according to the promoters of the course, "Most [Americans] can only read what is translated and what our Japanese competitors want us to read."

The program is emphatically not for beginners. It requires a solid foundation in Japanese (at least three years of college-level

study) in addition to mastery of the target technical field.

The courses will run from June 13 through Aug. 5, and have a tuition of $3300. The application deadline is March 15, 1994. *Contact: Susan L. Sherwood, Technical Japanese Language Project, MIT Japan Program, E38-762B, Cambridge, MA 02139; 617-253-8095; fax, 617-258-7432; e-mail, sherwood@mit.edu; or* **circle 104.**

INSTRUMENTATION

Chart recorder analyzes data

All too often, getting a chart recorder to capture data is easier than figuring out what the data means. So Astro-Med Inc., the makers of the MT95K2 32-channel recorder, decided to include a software analysis package in the machine so users could manipulate and analyze their waveforms.

Besides adding and subtracting waveforms, calculating the area under a curve, and applying a wide variety of filter functions to recorded data, the software can be set to search for and call attention to changes in signal amplitude or slew rate.

In addition, the MT95K2 has a vacuum fluorescent monitor, located directly above the chart, that displays signals in real time. Waveforms cascade down the monitor to corresponding tracings on the chart.

The recorder digitizes from 8 to 32 analog inputs at rates up to 200 kilosamples per second. It has a top chart speed of 500 mm/s.

Pricing for the instrument starts at $16 000; delivery takes four weeks. *Contact: Astro-Med Inc., Astro-Med Industrial Park, West Warwick, RI 02893; 800-343-4039; or* **circle 105.**

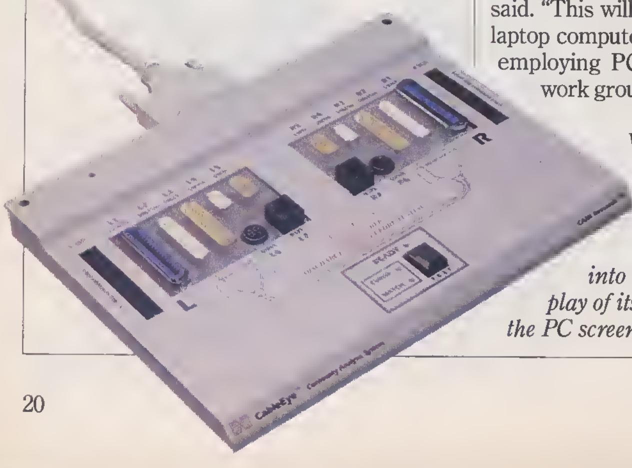
Checking out computer cables

The old saw about books applies equally to computer cables: you can't always judge them from the outside. Not only may a cable be flawed, its internal wiring may not match that of other—apparently identical—cables.

So how is a system integrator to know for sure what type of cable he has in his hand, and whether it is good? With the CableEye from Cami Research Inc.

The CableEye is a PC-based cable tester that uses the PC as its display device. It includes a database of more than 100 standard cable types. If a tested cable matches one of the descriptions in the database, the CableEye system will display descriptive notes explaining, among other things, the cable's usual application. If an exact match cannot be found, the user may search for similar cables, and then invoke the system's DISPLAY WIRING function to compare the wiring diagram of the cable under test with that of the standard cable.

CableEye includes provision for integration with automatic test systems. It also will save descriptions of their custom cables in the database. CableEye sells for $1495; it is available now. *Contact: Cami Research Inc., 442 Marrett Rd., Lexington, MA 02173; 617-860-9137; toll-free, 800-776-0414; fax, 617-860-9139; or* **circle 106.**



Verifying the type and condition of a computer cable is fast and easy with the PC-based CableEye from Cami Research Inc. Just plug it into the interface box, and a display of its wiring diagram appears on the PC screen.

PERIPHERALS

Wireless printer connections

One of the irritating aspects of sharing peripherals among several computers is the wiring. Installing it is a pain, and once installed, it tends to dictate how offices are set up.

People who dislike having their desk and seating arrangements decided by inanimate objects will appreciate LightShare-16 from Radiance Communications Inc. The product is a wireless infrared device that allows up to 15 IBM-compatible PCs to share a printer or other parallel-port device. It works at distances of up to 30 meters, and has a throughput of 250 kb/s.

The LightShare-16 is especially appropriate for environments that are difficult or impossible to wire, like manufacturing clean-rooms; for situations in which pulling wires would make too much dust; and in buildings without dropped ceilings. It is of obvious advantage to work groups that frequently reconfigure their floor plans, and is especially valuable for creating temporary work groups—at trade shows and conferences, for example.

According to chief executive officer Youngsoo Ryu, Radiance will soon extend LightShare-16 to mobile computing devices. "We expect to adapt the LightShare-16 to the PCMCIA [Personal Computer Memory Card International Association] standard," Ryu said. "This will make it possible to connect laptop computers and other mobile devices employing PCMCIA to a shared-printer work group." LightShare-16 is priced at $195 per computer station. *Contact: Radiance Communications Inc., 2338 A Walsh Ave., Santa Clara, CA 95051; 408-980-5360; toll-free, 800-980-9808; fax, 408-496-1214; or* **circle 107.**

DIGITAL SIGNAL PROCESSING

Board acquires, processes 16-bit data

Most data-acquisition applications that require 16-bit resolution have to process the acquired signals a fair amount—filter them, for example. What could be more natural, then, than to combine on one PC-compatible board 16 channels of 16-bit analog-to-digital conversion and a digital signal processor (DSP), as Microstar Laboratories Inc. has done on its DAP2416e/4 and -/6?

The two boards differ mainly in the size of their on-board RAM and in the clock rate of their DSPs. Those specifications are 6 kB and 20 MHz for the e/4; 96 kB and 32 MHz for the e/6. A third board, the DAP1216e/4 also provides 16 channels of 16-bit a-d conversion, but lacks a dedicated DSP chip. All three units are controlled by on-board 80C188 processors with 1.024 MB of RAM.

Prices for the individual boards range from $2495 to $3695. *Contact: Microstar Laboratories Inc., 2265 116th Ave. NE, Bellevue, WA 98004; 206-453-2345; fax, 206-453-3199; or* **circle 109.**

AUTOMATION

Robot design contest

On Sunday, April 17, the Science Center of Connecticut is sponsoring an international robot contest to top off its four-month robotics exhibit. The challenge will be to build a robotic device that can move through a model house, find a lit candle, and extinguish it. The winner will be the robot that does this in the shortest time.

Anyone may enter the contest, which will have various classes so that any robot, regardless of its sophistication, will have a chance at winning. All entrants will receive some sort of award, with $1000 going to the top winner.

The model house will have a single 2.4-by-2.4-meter floor, with walls, hallways, and rooms. The robots must be less than 30 cm on a side, and may be completely self-contained or tethered to a personal computer.

Contestants will be given the exact layout of the house along with the official rules. *Contact: Jake Mendelssohn, Science Center of Connecticut, 950 Trout Brook Dr., West Hartford, CT 06119; 203-231-2824, ext. 46; fax, 203-232-0705; Prodigy, KJRP71A; or* **circle 108.**

COORDINATOR: Michael J. Riezenman
CONSULTANT: Paul A.T. Wolfgang, Boeing Defense & Space Group

Faults & Failures

EMI in the sky

Every so often, an aircraft's communication, navigation, or monitoring equipment malfunctions, and sometimes a portable electronic device is blamed. A report due out this summer should clarify the issue.

The portable devices under suspicion range from compact disc players to cellular phones and laptop computers. The aircraft systems affected can be anything from indicators of exhaust gas temperature to navigation instrumentation.

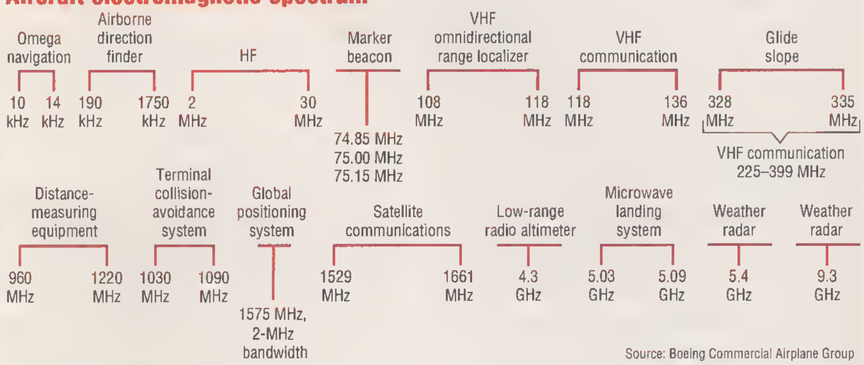
In one instance, the crew of a passenger airplane enroute from Newark Airport in New Jersey to Saint Maartens in the Netherlands Antilles noticed gross navigational errors on both of the craft's Omega (low-frequency en-route) navigation instruments. The two Omega sets disagreed with each other and were also inconsistent in time and heading with the plane's last known position. What saved the day was a weak VHF omnidirectional range (VOR) signal from Bermuda indicating that the plane was east of its intended route. As weather radar was the most reliable navigation information on hand, the crew used it to land in Bermuda. Subsequent investigation revealed that a passenger had been watching a portable TV.

Another incident ended in the arrest of a laptop user. On a flight from New York City's La Guardia airport to Chicago's O'Hare, the captain observed interference on the navigational equipment during takeoff. When the flight crew checked the cabin, they found a passenger using a laptop computer and asked him to turn it off. Some time later, when the same navigational problems recurred, the flight attendants discovered that the same man had again turned on his laptop. On arrival at O'Hare, as the plane was descending after a long delay and amid severe weather, the VORs again had problems. Once more the passenger had turned his computer on. He refused repeatedly to turn it off until the captain finally took it away and had the pigheaded passenger arrested for disorderly conduct when the aircraft landed.

Reports of such incidents are very few in relation to the large number of commercial flights and the popularity of portable devices. But they continue to trickle in.

For this reason, the Federal Aviation Administration (FAA) is looking into the testing of portable electronic devices that are likely to be taken along on a flight. As before, it has asked RTCA Inc. to establish test criteria, and RTCA plans to issue its final report this summer. The not-for-profit organization is based in Washington, D.C., and recommends standards and offers guidance to the aviation industry.

Aircraft electromagnetic spectrum



The issue of interference from portable electronic devices is a complicated one. The electromagnetic spectrum used by aircraft stretches from dc for certain monitoring equipment up to 10 GHz for weather radar [see figure]. The range of frequencies emitted by the carry-on units is almost as broad. The local oscillators of AM radio receivers generate signals in the 1 MHz range, while those of UHF TV receivers are up to 800 MHz. In between a plethora of devices emit signals from 1 to 66 MHz. Laptop computers operate from 25 to 66 MHz. Many other products, like electronic games and electronic personal organizers, contain microcontrollers that operate in the same frequency range. Compact disc players and camcorders have also been found to emit radiation in the megahertz regime. Moreover, the harmonics of these emissions are also important.

To further confuse the situation, the electromagnetic environment of the aircraft during the time of the interference may play a critical role. To quote John Sheehan, who chairs the RTCA committee studying the subject: "There's a lot of electronic soup at low altitudes, particularly around airports—microwave, radar, anything in the electromagnetic spectrum—and some at fairly high intensities. What does that do to the weak signal from the [portable electronic device] relative to the aircraft systems? I suspect it is a major part of the problem."

But perhaps the most frustrating aspect of the problem is its nonrepeatability. "There are only a few cases where we can directly tie a [portable electronic unit] to an abnormal indication in the cockpit," Todd Degner, manager of avionics engineering for American Airlines, told *IEEE Spectrum*. "I can think of no more than two or three instances where the crew allowed the passenger to turn the device back on and the problem reappeared."

Even in these instances, attempts to repeat them on the ground have usually failed, despite the use of "the same device, the same aircraft, and the same crew," said Sheehan. RTCA in an earlier report issued in 1988, recommended additional regulations to the FAA and the Federal Communications Commission (FCC) that were not acted upon. These included banning the use of all electronic units below 3000 meters and banning the use entirely of such intentional radiators as cellular phones and remote-control devices. Recently, though, these precautions have been voluntarily adopted by the airlines.

In its current study, RTCA is taking another look at the issue in light of the proliferation of devices that have come into existence in the 10 years since its second study began. In all, three samples each of 25 different devices will be tested with a three-pronged approach. First, laboratory measurements will determine the devices' electromagnetic emission signatures. Second, the emission patterns will be recreated aboard aircraft, to see if they cause interference to the instrumentation. The third phase, modeling, is unique to the current study. Sheehan hopes to shed new light on the effect by incorporating models of portable electronic devices into existing military models of aircraft in external electromagnetic environments.

Meanwhile, evidence for instances of interference due to the operation of electronic units remains scant, incomplete, and inconclusive. To fill out the picture, RTCA is disseminating a reporting form to the aviation industry. The form, which is voluntary and confidential, can be obtained from the organization at 202-833-9339.

Linda Geppert

Vital signs of identity

Biometrics is emerging as the most foolproof method of automated personal identification in demand by an ever more automated world

Identifying a person seems straightforward—people do it all the time in business and social encounters. But modern society has complicated things, most notoriously when a welfare recipient signs up for benefits under six identities, a child is released to a stranger from a day care center, a hacker accesses sensitive databases, a counterfeiter makes copies of bank cards, and the murderer switches places with the car thief leaving prison on a work release.

At all levels, a sure-fire means of identification has never been more in demand. Today, the average businessperson may use more than a dozen computer passwords—personal identification numbers (PINs) for automated teller machines, licenses, and telephone calling, membership, and credit cards. Ten years ago, he or she probably had only a few. Yet finding satisfactory methods of identifying employees or customers can be difficult. Some techniques are easy to fool, some are too expensive, and others are felt to be too intrusive.

One area where technology is enhancing, and often simplifying, our ability to identify people is biometrics. Biometric systems are automated methods of verifying or recognizing the identity of a living person on the basis of some physiological characteristic, like a fingerprint or iris pattern, or some aspect of behavior, like handwriting or keystroke patterns.

While biometrics is being applied both to identity verification and to identity recognition, the problems each involves are somewhat different. Verification requires the person being identified to lay claim to an identity, so that the system has a binary choice of either accepting or rejecting the person's claim. Recognition requires the system to look through many stored sets of characteristics and pick the one that matches the characteristics of the unknown individual being presented, a more difficult task.

Benjamin Miller *Personal Identification News*

A range of biometric systems is in development or on the market, because no one system meets all needs. The tradeoffs in developing these systems involve component cost, reliability, discomfort in using a device, the amount of data needed, and other factors. Fingerprints, for example, have a long history of reliability, but the electronic imaging components required for capturing a fingerprint cost hundreds of dollars and the data describing a fingerprint, the template, is large. In contrast, the tools required to capture a signature—some sort of pen or stylus and tablet—are low in cost, and the template is very small; but signatures are not as stable as fingerprints, varying with people's emotional state, for example. Voice, too, is cheap to capture, relying on low-cost microphones or existing telephones, but varies when emotions and states of health change, and has a large template size.

NEEO FOR ACCEPTABILITY. Psychological factors also come into play when researchers consider biometrics for different applications. Eye recognition, for example—both retina scanning, which requires close contact with the recognition device, and iris scanning, which can be done from a more comfortable distance—disconcerts some people because of an inherent protectiveness about their eyes. Quite the contrary, hand recognition, in which the palm is placed on a plate, appears not to bother people, perhaps because shaking hands is common behavior. But in some applications, eye recognition's psychological effect is a benefit—it appears to be a very serious recognition method and this seriousness may in itself discourage intruders.

While advances in biometric technology are snowballing, though, the market itself is growing slowly. Only a few high-quality products are being shipped and prices, typically US $2000 per point of identification, are too high for many applications. Potential users of biometrics—in areas ranging from banking to government, health care, and business—see clear benefits in the technology, but need reliable devices at affordable prices. They want systems that rarely reject authorized individuals, catch most impostors, and cost under $500. With the healthy pace of research and development under way, it is simply a matter of time before these goals are reached and biometrics become commonplace.

Before examining some biometric approaches, however, it is useful to understand the concepts of identification. A straightforward model of the process postulates three building blocks: something a person knows (a code), or possesses (a card), or has (a characteristic). From this static model can be derived a much more dynamic model for an identification scheme that balances such variables as types of threat, value being protected, user reaction, and of course cost [Fig. 1].

Different situations warrant different approaches to identification. The three basic ID methods may be combined to give varying levels of protection. The model can be changed by technology in two ways—automation and migration.

Automation may be applied to an existing process to reduce cost, improve quality, or handle higher volume. Today, for instance, picture ID badges, driver's licenses, and some bank credit cards are produced by electronic video-imaging systems instead of still cameras. Videocameras linked to PCs and modern color printers not only issue an ID credential, but also store the image in a computer. This processing hardly changes the behavior of the person being identified, who must still present his or her face and a credential to be identified; but it greatly enhances the ID operation.

While automation changes are generally internal to the organization and affect the identificand only slightly, migration affects both internal operations and the identificand. It occurs when the identification scheme is moved to a different section of the ID model. This move may be made to boost security levels, to speed throughput or capacity, to reduce cost, or to add convenience. Presenting a biometric X at an access point and requiring a PIN for credit card transactions are examples of new positions in the model. It means that care must be given to training those who will be identified because their behavior is now being affected.

As the Fig. 1 model demonstrates, biometrics for the foreseeable future will not eliminate the need for cards, passwords, and PINs. Predictions to the contrary have hurt the biometrics industry when it failed to live up to unrealistic expectations. Today, according to *Personal Identification News,* the industry generates about $12 million a year in sales of identity verification products (and exceeds $100 million when electronic fingerprint equipment used by law enforcement agencies is included).

BIRTH OF BIOMETRICS. Biometrics dates back to the ancient Egyptians, who measured people to identify them. But automated biometric devices appeared within living memory;

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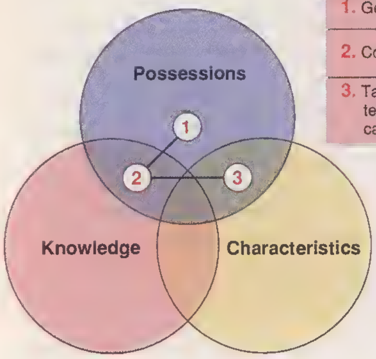


Access to:	ID	Per-door cost	Asset value in dollars
1. General area	Smart card	$400	Thousands
2. Computer rooms	Smart card and PIN*	$600	Millions
3. Tape vaults and telecommunications area	Smart card and fingerprint	$5000	Billions

*Personal identification number

Most important requirements
Security levels
System throughput
User acceptance

Source: Warfel & Miller Publishing Co.

[1] This system, which controls access to a credit card processing facility, employs not only fingerprint biometrics for its most secure areas, but also a state-of-the-art card that attaches an integrated circuit chip to a plastic photo ID badge. The chip stores the fingerprint image, the personal identification number (PIN), and security levels. The microprocessor in the card compares PINs and authenticates itself to the reader terminals.

one of the first commercial devices was introduced under 30 years ago. Called the Identimat, the machine measured finger length and was installed in a time-keeping system at Shearson Hamill, a Wall Street investment firm. Subsequently, hundreds of them were installed at highly secure facilities run by Western Electric, U.S. Naval Intelligence, the Department of Energy, and like organizations.

Worldwide there are now over 10 000 computer rooms, vaults, research laboratories, day care centers, blood banks, jails, airports, military installations, and even college cafeterias that use devices that identify people from physiological or behavioral characteristics unique to them. Biometrics is also catching on in computer and communication systems, as well as automated teller machines (ATMs). Still, it is a steady technology evolution, not a revolution, that is under way.

Biometric devices have three primary components. One is an automated mechanism that scans and captures a digital or analog image of a living personal characteristic. Another handles compression, processing, storage, and comparison of the image with the stored data. The third interfaces with application systems. These pieces may be configured to suit different situations. A common issue is where the stored images (reference templates) reside: on a card, presented by the person being verified, or at a host computer.

Recognition occurs when an individual's image is matched with one of a group of stored images. This is the way the human brain performs most day-to-day identifications. For the brain, this is a relatively quick and efficient process, whereas for computers to recognize that a live image matches one of many it has stored, the job can be time consuming and costly.

The most complex and expensive systems, with huge databases of more than a million stored images, are used by police agencies. The Federal Bureau of Investigation's Integrated Automated Fingerprint Identification System, for example, stores 40 terabytes of data. Such organizations are willing to foot the bill because the multimillion-dollar systems clearly save lives and help protect society. The automated fingerprint identification systems (AFISs) are the most widespread application of biometric technology, and have helped to apprehend tens of thousands of criminals.

Recently, costs for these systems have begun to drop, and they are being considered for other than law enforcement uses as well. Los Angeles County, for instance, uses such a system to ensure that welfare recipients apply for benefits only once. Some progress has also been made in basing lower-cost identity recognition systems on increasingly powerful PCs, and several companies are employing neural networks in the recognition of faces, fingerprints, voices, and signatures. But for most applications today, recognition systems that rely on exhaustive database searches are just too much.

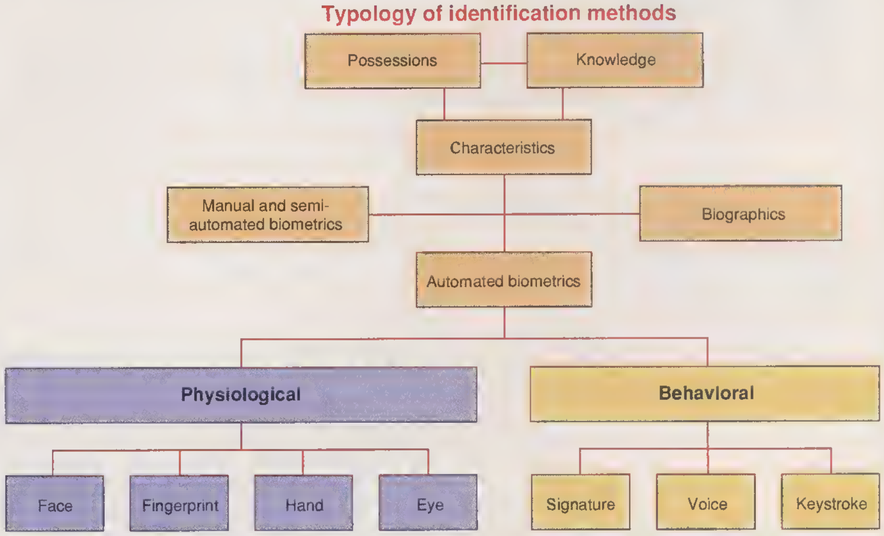
The lion's share of biometric devices instead depends on a verification system, which requires the user to lay claim to an identity by presenting a code or a card. A formula or algorithm for matching two items then compares the live and enrolled images of the user's characteristic. The question put by the machine is, "Are you who you say you are?" instead of "Do I know who you are?"

Indispensable to all biometric systems is that they recognize a living person. One of the first questions newcomers to the field ask is, "What about a counterfeiting attempt using a latex finger, digital audio tape, plaster hand, prosthetic eye, and so on?" To prevent such fraud, many, but not all, devices include methods for determining whether a live characteristic is being presented. The methods are sometimes ingenious but usually simpler than would be expected. Several companies are working on devices that will be very difficult to fool: for instance, an iris-scanning system soon to be released will look at characteristic patterns in the flecks of the iris, an infrared system for checking veins will look at flows of warm blood, and ultrasound fingerprint readers will look at subcutaneous structures.

Biometrics encompasses both physiological and behavioral characteristics [Fig. 2]. A physiological characteristic is a relatively stable physical feature such as a fingerprint, hand silhouette, iris pattern, retina pattern, or facial feature—all these are basically unalterable without trauma to the individual.

A behavioral trait, on the other hand, has some physiological basis, but also reflects a

Typology of identification methods



Source: Warfel & Miller Publishing Co.

[2] Personal characteristics—physiological and behavioral—may serve as the basis for biometric identification. Physiological characteristics vary little from time to time, but their use may be considered threatening in some applications. Behavioral characteristics may be hard to measure because of influences such as stress, fatigue, or colds, but they seem more acceptable to users and generally cost less to implement in a system.

person's psychological makeup. The most common trait used in identification is a person's signature. Other behaviors used include a person's keyboard typing and speech patterns. Because most behavioral characteristics change over time, many biometric machines that rely on behavior update their enrolled reference template each time they are used. After many successful accesses, the template may differ significantly from the original data, and the machine become more proficient at identifying the person. Behavioral biometrics work best with regular use.

The differences between physiological and behavioral methods are important. For one, the degree of intrapersonal variation is smaller in a physical characteristic than in a behavioral one. Barring injury, after all, a person's fingerprint is the same day in and day out, whereas a signature is influenced by both controllable actions and unintentional psychological factors.

Developers of behavior-based systems, therefore, have a tougher job adjusting for an individual's variability. For example, it is easier to build a machine that guides you in placing your hand in the same position every time than it is to write algorithms that take into account emotional states or the sniffles. However, machines that measure physical characteristics tend to be larger and more expensive, and may seem threatening to users. Behavior-based biometric devices are often smaller, cheaper, and more friendly. Either technique affords a much more reliable level of identification than passwords or cards alone.

Because of these differences, no one biometric will serve all needs. A company may even decide to use different techniques in different parts of its operations. For example, voice verification may be used in the executive suites while fingerprints are used in the computer rooms.

TIGHTENED TOLERANCE. The most commonly discussed measure of a biometric's performance is its identifying power. This measure

HAND: give me five

The three-dimensional shape of a person's hand has several advantages as an identification device. It is fast—scanning a hand and producing a result takes 1.2 seconds or so. It requires little room for data storage—about 9 bytes, which can fit easily on magnetic-stripe credit cards. Little effort or attention is required on the user's part, and the authorized user is rarely rejected. Above all, people like it, according to recent tests by Sandia National Laboratories, Albuquerque, N.M.

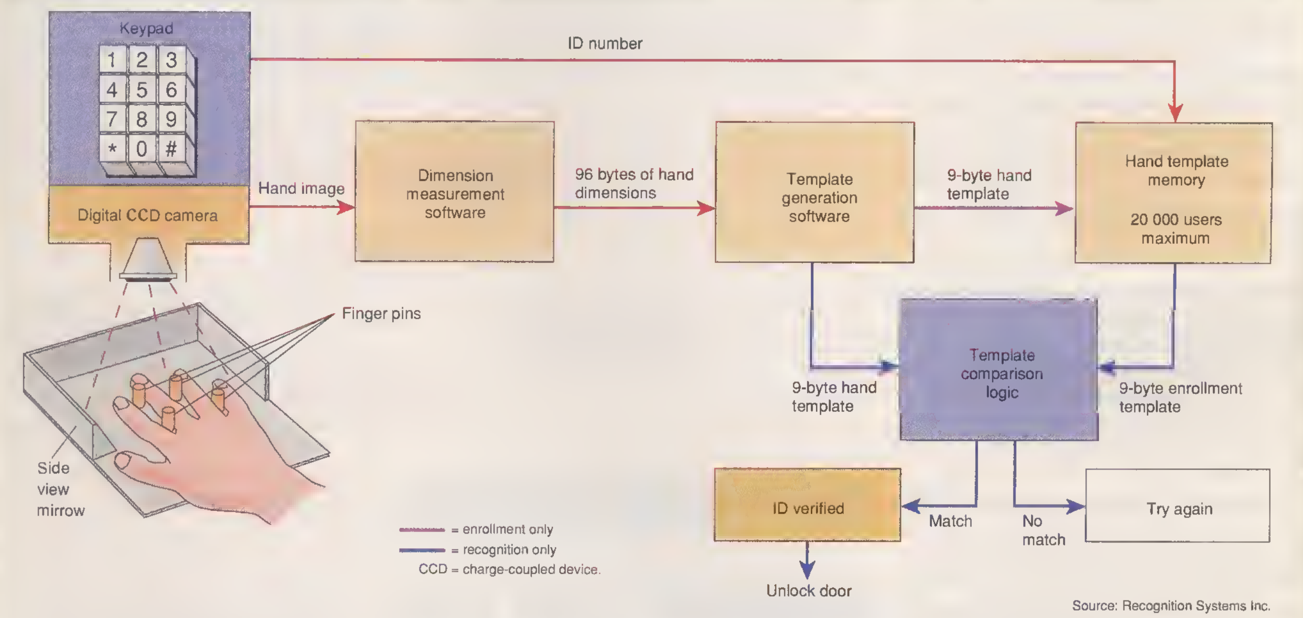
Only one hand geometry identification device is commercially available: the ID3D Handkey, which was developed by Recognition Systems Inc., Campbell, Calif. The user punches in an identification code, then positions his or her hand on a plate between a set of guidance pins. Looking down upon the hand is a charge-coupled-device (CCD) digital camera, which with the help of a mirror captures the side and top views of the hand simultaneously [see figure].

The black-and-white digital image is analyzed by software running on a built-in HD64180 microprocessor (a Z-80–based chip) to extract identifying characteristics from the hand picture. The software compares those features to features captured when the user was enrolled in the system, and signals the result—match or no match.

Analysis is based upon the measurement and comparison of geometries. The magnification factor of the camera is known and is calibrated for pixels per inch of real distance. Then the dimensions of parts of the hand, such as finger length, width, and area, are measured, adjusted according to calibration marks on the platen, and used to determine the identifying geometries of the hand.

A strong correlation exists between the dimensions of the hand. For example, if the little finger is long, the index finger will most likely also be long. Some 400 hands were measured to determine these interrelationships, and the results are integrated into the system as a set of matrices. These matrices are applied to the measured geometries to produce the 9-byte identity feature vector that is stored in the system during enrollment. With this amount of data compression, the current 4.5-kg unit, with a single printed-circuit board, can store 20 000 identities.

Enrollment involves taking three hand



In the ID3D Handkey from Recognition Systems Inc., a set of pins on a plate guides the hand into position. A mirror allows the camera to capture the side and top views of the hand simultaneously. Software running on a Z-80–based microprocessor analyzes the digital image, extracts identification features, and creates a 9-byte hand template, stored in the system along with the user's personal identification number, entered on the keypad. To verify identity, the user enters his or her code and positions a hand between the pins, whereupon the system creates a new template for comparison with its database of existing templates.

is defined by a slippery pair of statistics known as false rejection rate (FRR) and false acceptance rate (FAR). To set the desired balance of FAR and FRR, many machines have variable thresholds. If this tolerance setting is tightened to make it harder for impostors, some authorized people may find it harder to gain access. Conversely, if it is easy for rightful people to gain access, then the frightful may slip through.

On the first few attempts, a user typically has to sacrifice some false rejections to get near-perfect protection against impostors. The most balanced biometric device available today, the ID3D hand geometry machine from Recognition Systems Inc., Campbell, Calif., has scored FRR-FAR crossover of less than 0.2 percent in independent tests.

Although developers continue to work on techniques to reduce FRR, improvements become more elusive as the percentage of problem cases falls. Most early adopters of biometrics have found that training people in using the machines effectively is the best way to reduce false rejections. Most have also found that false reject rates drop markedly after two weeks of use.

PHYSICAL FACTORS. Identification systems on the market or in development today employ a variety of biometric approaches.

Hand geometry is the granddaddy of biometrics by virtue of its 20-year history of live applications. Over this span, six hand-scanning products have been developed but only one commercially viable product is currently available, the ID3D HandKey mentioned previously [see "Hand," below left]. Using a built-in videocamera and compression algorithms, it looks at both the top and side views of the hand. The reference template needs under 10 bytes, the smallest in the industry. Dirt and cuts do not detract from performance, and the hand is easily guided into the correct position for scanning.

Hand geometry is employed at over 4000 locations, including the Colombian legislature, the San Francisco International Airport, a day care center at Lotus Corp., and a Los Angeles sperm bank. Cost of the unit starts at $2150. Four other devices that look at other hand features are also under development by such companies as Biomet Partners, Biometrics, Pideac, and Dactylometrics International.

For general security and computer access control applications, fingerprints are gaining popularity. As might be expected, fingerprint verifiers are installed at military facilities like the Pentagon and government laboratories, but banks, jails, and commercial entities have also been early adopters.

The fingerprint's stability and uniqueness is well established. Based upon a century of examination, it is estimated that the chance of two people, including twins, having the same print is less than one in a billion. In verifying a print, many devices on the market analyze the position of details called minutiae, such as the endpoints and junctions of print ridges. These devices assign locations to the minutiae, using *x*, *y*, and directional variables. Some devices also count the number of ridges between the minutiae to form the reference template. Several companies claim to be developing templates of under 100 bytes. Other machines approach the finger as an image-processing problem and apply custom very large-scale integrated chips, neural networks, fuzzy logic, and other technologies to the matching problem [see "Fingerprint," next page].

These image-based systems require data templates of 500–1500 bytes, depending on the approach and security level required. Systems are generally priced in the $1995–$3500 range, depending on configuration, and a number of systems are available offering integration with smart cards for template storage that the user would carry. The machines now on the market tend to reject over 3 percent of authorized users in independent tests, while maintaining far lower false acceptance rates of less than one person in a million.

Fingerprints have overcome the stigma of their use in law enforcement and military applications. While some applications do steer clear of the technology for this reason, others actually build on the mystique, which seems to shout, "Identification is taken seriously here!" As a result, more than a dozen companies around the world are work-

readings and averaging the resulting vectors. Users can enroll themselves with minimal help. When used for identification, the 9-byte vector is compared to the stored vector and a score, based on the scalar difference, is stored. Low scores indicate a small difference, high scores mean a poor match.

The Recognition Systems product fine-tunes the reference vector a small increment at a time, in case the original template was made under less than perfect conditions.

Other systems for hand recognition have been attempted in the past, but few came to market. One was an effort by SRI International, funded by the Air Force, and purchased in the early 1980s by Esselte Ltd. of Solna, Sweden, to take pictures of unconstrained hands held up in free space. This system was introduced in 1985.

Biometrics Inc., Sunnyvale, Calif., made an earlier attempt at the technology that read the creases on the inner side of the fingers. In 1991 Tokyo's Toshiba Corp. demonstrated a finger crease scanner, but apparently is not commercializing the development. And Personnel Identification & Entry Access Control Inc., in Yellow Springs, Ohio, received US $1 million in government funding to develop a hand reader based on two-dimensional imaging: the hand was placed on a flat plate, with no constraints on its position. That project also never succeeded in passing the prototype stage.

The one other system that was commercialized was the Identimat hand geometry reader, developed by Identimation Corp., Northvale, N.J., in the 1960s. Here, an electromechanical scanner based on photoelectric cells measured the lengths of the four fingers. Used primarily in the nuclear weapons industry, it was retired in 1987. The Recognition Systems implementation was introduced in 1986, and is now in its third generation.

This method of hand geometry identification is obvious to users and is easy to integrate into existing systems because of the minimal computer memory requirements. The 9-byte IDs may be stored in the system or remotely, and, if remote, do not require high transmission rates. The IDs may also be encoded on magnetic-stripe cards, with bar codes or optical character recognition for stand-alone use. System cost is low: a station that can recognize 256 hands retails at $2150. Inexpensive plug-in modules expand the capacity to 20 000 hands, or the hand reader can be connected to a computer for virtually unlimited capacity.

The system's limitation is the size of the device. Since it must accommodate most hands, it cannot be built into a keypad or doorknob. In principle, one could fool the device by capturing a person's hand geometry, discovering the ID number, and creating a fake hand. In practice, however, it is much more resistant than conventional security measures like pass cards, codes, and keys.

The ID3D Handkey is being used all over the United States. In the University of Georgia, it tracks meal plan use. At San Francisco International Airport, it helps control access to operations. At Lotus Development Corp., it keeps unauthorized visitors out of its day care center. At the Federal Bureau of Prisons in Jessup, Ga., it checks visitors. It assists in L.L. Bean Inc.'s catalog operation and at ITS Inc., an international airport services supplier, in verifying employee identity for time and attendance recording. It is also in use at Kennedy and Newark International Airports for automated passport inspection and entry control of people who have registered as frequent international travelers. In South America, too, it is used in the Colombian House of Representatives and Senate to eliminate voting fraud. —*Dave Sidlauskas*

The author is president of Recognition Systems Inc., Campbell, Calif., which was founded in 1986 to develop and market biometric devices based on hand geometry. He previously worked as executive vice president for Stellar Systems Inc., vice president of engineering for Schlage Electronics (now Westinghouse Security Electronics), technical director of Oximetrix, and a research engineer for Hewlett-Packard Co. Sidlauskas holds six patents for various aspects of identification systems.

ing on new fingerprint identification systems, and most claim their systems will offer better FRR performance, lower cost, and smaller templates.

Two other methods of identification involve the eye, scanning the blood vessel pattern on the retina and examining the pattern of the structure of the iris. Only one company, Eyedentify Inc., Baton Rouge, La., produces retinal scan products. The company has struggled for over a decade, but new owners are working to improve marketing and reduce costs. No others are expected to enter the field.

Retina scans, in which a weak infrared light is directed through the pupil to the back of the eye, have been commercially available since 1985. The retinal pattern is reflected back to a charge-coupled device (CCD) camera, which captures the unique pattern and represents it in less than 35 bytes of information. Most installations to date, currently costing \$4000–\$5000, have involved high-security access control, including numerous military and bank facilities.

Retina scans are one of the best biometric performers on the market, with low false-

FINGERPRINT: an old touchstone decriminalized

Perhaps most of the work in biometric identification has gone into the fingerprint. It was an obvious target for automation, since police have for a century used it to identify criminals. For most of that time, the prints were laboriously matched by human experts. The first commercial automated system had its origins in 1971, in the garage of the author, then a spacecraft engineer at TRW Inc. The technology was developed for some 12 years before being marketed in 1983 by Identix Inc., Sunnyvale, Calif.

Algorithms for the automated identification of criminals' fingerprints were developed in the 1950s by the Federal Bureau of Investigation (FBI) in concert with the National Bureau of Standards, Cornell Aeronautical Laboratory, and Rockwell International Corp. A decade later, Tokyo's NEC Technologies Inc., Printrak Inc. of Anaheim, Calif., and Morpho Systems, Paris, entered the field basing their efforts on the earlier work by the FBI.

Some newcomers to the field are looking into the suitability of neural network techniques. A British joint effort by ICL PLC and Cambridge Neurodynamics Ltd. is called Anadactyl; another is at Orincon Corp., San Diego, Calif.

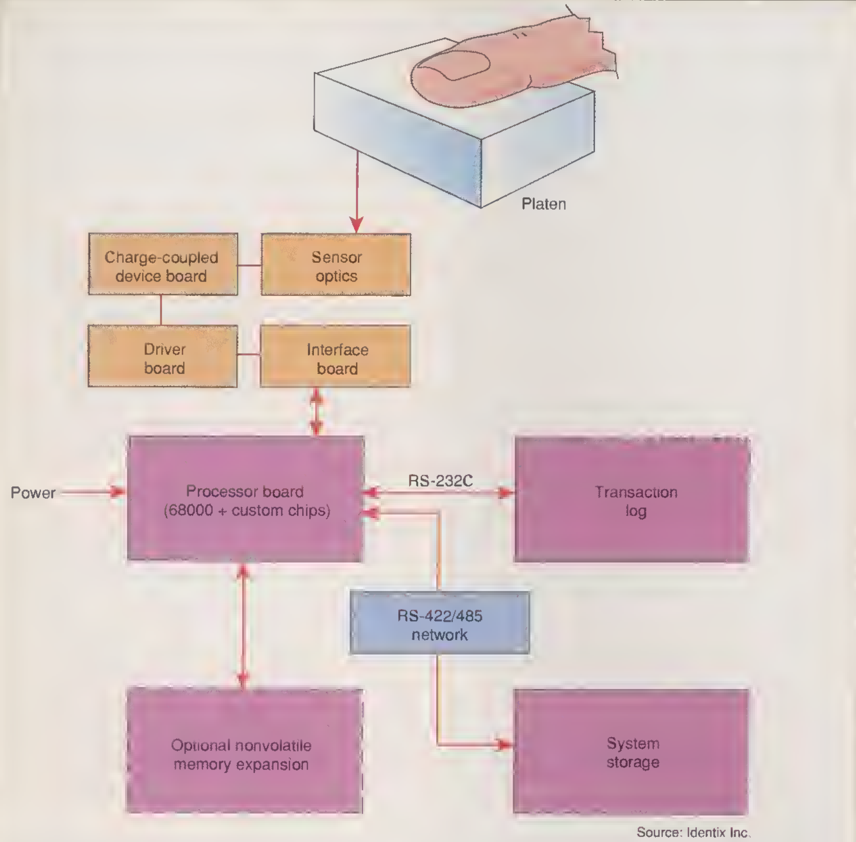
The Identix system uses a compact terminal that incorporates light, lens, and charged-coupled-device (CCD) image sensors to take a high-resolution picture of the fingerprint. It is based on a 68000 central processing unit (CPU) with additional custom chips, but can also be configured as a peripheral for an IBM PC; it can operate as a standalone system or as part of a network.

To enroll, a user is assigned a personal identification number and then puts a single finger on a glass or plexiglass plate for scanning by a CCD image sensor. The 250-kilobyte image is digitized and analyzed, and the result is an approximately 1-kilobyte mathematical characterization of the fingerprint. This takes about 30 seconds. Identity verification takes less than 1 second. The equipment generally gives the user three attempts for acceptance or final rejection. With the first attempt, false rejection is around 2–3 percent; false acceptance is less than 0.0001 percent. Each standalone unit can store 48 fingerprint templates, which may be expanded to 846 by installing an additional memory package. The equipment ranges in price from a few hundred dollars to several tens of thousands, depending on the application and the number of terminals to be networked.

Fingerprint recognition is appropriate for many applications, and is a familiar idea to most people, even if only from crime dramas on television. It is nonintrusive, user friendly, and relatively inexpensive.

Currently, the Identix system is being used in over 40 countries. Its applications include controlling access to physical space in the Pentagon and to computers in the financial networks of Italy; automated banking terminals in Australia; customs and immigration applications in Amsterdam; and inmate and visitor control in Maryland's prison system. It was also used as an access control system for several hundred thousand season-pass holders at Expo '92 in Seville, Spain.

Another Identix product called TouchPrint is being used as one of the input devices for an interstate criminal identification system. The fingerprint data in these cases is transmitted over telephone lines and local-area networks. —*Randall C. Fowler*



Identix Inc.'s system for recognizing fingerprints requires the user to press a finger onto a glass or plexiglass platen. Image sensors under the platen and a charge-coupled-device (CCD) array capture the fingerprint image. A custom computer system and software analyzes the digitized image and converts it to an approximately 1-kilobyte mathematical characterization, which is compared against data stored in the local terminal or, in networked versions of the system, in a remote personal computer.

A former chairman of the International Biometrics Association, the author is president and chief executive officer of Identix Inc., Sunnyvale, Calif., which was established in 1982. Fowler held previous management or engineering positions with System Development, Lockheed Missiles & Space, TRW, Motorola Military Electronics, Goodyear Aerospace, and San Jose State University.

IRIS: more detailed than a fingerprint

Once it was the whites of their eyes that counted. Retinal pattern recognition has been tried but found uncomfortable because the individual must touch, or remain very close to, a retinal scanner. Now the iris is the focus of a relatively new biometric means of identification. Standard monochrome video or photographic technology in combination with robust software and standard video imaging techniques can accept or reject an iris at distances of 30–45 cm.

The technology being implemented by IriScan Inc., Mount Laurel, N.J., is based on principles developed and patented by ophthalmologists Leonard Flom and Aran Safir and on mathematical algorithms developed by John Daugman. The company holds the patents for both the iris recognition/identification concepts and the methodology, issued in 1987 and 1993, respectively.

In their practice, Flom and Safir observed that every iris had a highly detailed and unique texture that remains stable over decades of life. This part of the eye is one of the most striking features of the face. It is easily visible from yards away as a colored disk, behind the clear protective window of the cornea, surrounded by the white tissue of the eye. Observable features include contraction furrows, striations, pits, collagenous fibers, filaments, crypts (darkened areas resembling excavations), serpentine vasculature, rings, and freckles. The structure of the iris is unique, as is a fingerprint, but it boasts more than six times as many distinctly different characteristics as the fingerprint. This part of the eye, moreover, cannot be surgically modified without damage to vision, it is protected from damage or external changes by the cornea, and it responds to light, a natural test against artifice.

IriScan's existing prototype system utilizes a standard video camcorder as the video image source, a video frame grabber, and a Sun SparcStation for computational analysis. Analysis begins with a means for reliably finding the iris in the digitized video image. This entails the use of a series of integro-differential two-dimensional linear operators. Image quality is evaluated for focus, and eyelid occlusion is evaluated.

Zones of analysis are established within the iris image to extract textural information by means of two-dimensional Gabor filter functions, which offer the maximum possible resolution for information about spatial frequency, orientation, and 2-D position. The coefficients of the elementary 2-D Gabor transforms are extracted from the digitized image by neural

Every iris is uniquely textured with striations, furrows, and other details. In IriScan Inc.'s prototype iris recognition system, a videocamera and frame grabber capture and digitize an image of the iris. Signal processing and feature extraction establish zones of analysis [indicated in white] and a 256-byte code is computed and stored [bar code, upper left].

network techniques. As a result of the signal analysis, a 256-byte Iriscode is computed and stored as the file code for future comparison. The time required to compute an Iriscode after location of the iris is 100 ms or so.

The next step in recognizing the signature of a given iris as belonging to a specific person (file template) is formulated within the framework of statistical decision theory. The task is converted from pattern recognition to one of executing a simple statistical test. In order to perform the test, Hamming distances are generated from the Iriscode developed for the real-time image and from the Iriscode template from the stored file. In this case, the Hamming distance is a measure of error (fraction of disagreeing bits) resulting from a bit-by-bit comparison of the two Iriscodes.

The Hamming distance is used by the IrisScan system in making an accept or reject decision. The laboratory model is currently demonstrating a crossover error rate (where the false acceptances are equal to false rejections) of 1 error in 131 000. The decision criteria can be adjusted to enable the system to perform with a higher or lower false-accept or false-reject rate, depending upon the desired application.

This system is not yet on the market. Its developers are still adressing a number of human factors issues, including unusual applications for illumination, distance from the subject, and focusing. Extensive field testing will be conducted during the first half of 1994. Primary markets are expected to be security entry and access control; credit card and point-of-sale verification; computer and network security; passport and customs applications; and automatic teller machine and financial transaction verification. IriScan expects to begin shipping systems by the last quarter of 1994. —*John E. Siedlarz*

Currently president and chief executive officer of the three-year-old IriScan Inc., Mount Laurel, N.J., the author has been involved in the design, analysis, and engineering development of electronic security systems for over 24 years. He previously held senior or technical management positions at Technical Security Associates, Penn Central Technical Security Co., and The Vitro Corp.

reject rates and a nearly 0 percent false-accept rate. The technology also offers small data templates, provides quick identity confirmations, and handles well the job of recognizing individuals in a database of under 500 people. The toughest hurdle for retinal scan technologies is users' resistance—people do not want to put their eye as close to the device as necessary.

A device that examines the human iris is being developed by IriScan Inc., Mount Laurel, N.J. [see "Iris," above]. The technique's big advantage over retinal scans is that it does not require the user to move close to the device and focus on a target because the iris pattern is on the eye's surface. In fact, the video image of an eye can be taken at a distance of a meter or so, and the user need not inter-

act with the device at all. IriScan expects to provide its first products late this year.

Biometric developers have also not lost sight of the fact that humans use the face as their primary method of telling who's who. More than a dozen efforts to develop automated facial verification or recognition systems use approaches ranging from pattern recognition based on neural networks to infrared scans of "hot spots" on the face. Yet, despite the best efforts of organizations, including government research laboratories, machine vision companies, and satellite image-processing experts, only one system is available on the market today—from NeuroMetric Vision Systems Inc., Pompano Beach, Fla. [see "Face," below].

Despite the challenges involved in facial recognition—having to deal with beards, hair cuts, expressions, and the like—there is tremendous interest in the approach. Law enforcement agencies are eager to have a machine that could spot a known terrorist, drug dealer, or bank robber in a crowd. Physical security professionals would jump at the chance to build on their existing investments in closed-circuit television systems, and computer security mavens talk of a small videocamera built into PCs that would constantly check that the person sitting at the machine is the authorized user.

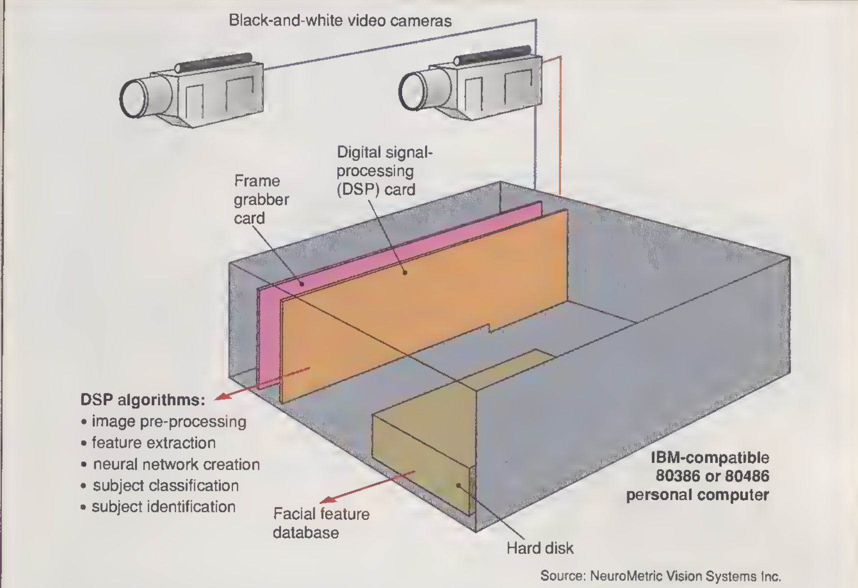
SPEAK OF THE DEVIL. Another biometric approach that is attractive because of its acceptability to users is voice verification. All the systems used in analyzing the voice are rooted in more broadly based speech-processing technology.

Several large organizations, including AT&T Bell Communications Research,

FACE: smile, you're on candid camera

Using the whole face for automatic identification is a complex task because its appearance is constantly changing. Variations in facial expressions, hair style and facial hair, head position, camera scale, and lighting create images that usually differ from the image captured on film or videotape earlier. The application of advanced image-processing techniques and the use of neural networks for classifying the images, however, has made the job possible.

Artificial neural networks were pioneered in the 1950s and 1960s. They are massively connected, parallel networks of simple computing elements. Their design mimics the organization and performance of biological neural networks in the nervous system and the brain. They can learn and adapt, and be taught to recognize patterns, both static and dynamic. Also, their interconnected parallel structure allows for a degree of fault tolerance as individual computing elements become inoperative. Neural networks are being used for pattern recognition, function approximation, time series analysis, and disk control.



The face recognition system developed by NeuroMetric Vision Systems Inc. is based on an IBM-compatible personal computer with a frame grabber and custom digital signal-processing card. The facial image is captured by a video camera and digitized. Software running on the card locates the face, scales and rotates it, and converts it to a set of vectors. These are input to a neural network for comparision against stored data.

Working on the face recognition problem, NeuroMetric Vision Systems Inc., Pompano Beach, Fla., developed a system that can recognize faces with as few constraints as possible, accommodating a range of camera scales and lighting environments, along with changes in expression and facial hair and in head position. The work sprang from the realization that such techniques as facial image comparisons, measurement of key facial features, and the analysis of facial geometry could be used in a face recognition system. Any of these approaches might employ rule-based logic or a neural network for the image classification process.

First introduced in 1992, the NeuroMetric system operates on an IBM-compatible 386 or 486 personal computer, with a math coprocessor, a digital signal-processing (DSP) card, and a frame grabber card to convert raster scan frames from an attached camera into pixel representations. The system can capture images from black-and-white video cameras or video recorders in real time.

Software running on the DSP card locates the face in the video frame, scales and rotates it if necessary, compensates for lighting differences, and performs mathematical transformations to reduce the face to a set of floating-point feature vectors. The feature vector set is input to the neural network trained to respond by matching it to one of the trained images in as little as 1 second.

The system's rejection level can be tuned by specifying different signal-to-noise ratios for the match—a high ratio to specify a precise match, and a lower one to allow more facial variation. In a tightly controlled environment, for example, the system could be set up to recognize a person only when looking at the camera with the same expression he or she had when initially enrolled in the system.

The image processing and its classification by the neural network are done on the system's DSP card, which recalls neural network clusters from the PC's disk when required. The current system can keep up to 5000 faces in its database and, with multiple DSP cards and video camera multiplexing, can identify up to 20 people per second. A second generation, expected to be launched by year end, will be able to work with databases of up to 50 000 images. Eventually, the system will accommodate a million faces. When searched for in databases of this size, a face should be found in 20 seconds to 2 minutes. Today's single-camera system with one DSP card, one frame grabber, and a database capacity of 5000 faces costs approximately US $30 000. A 16-door system would cost approximately $50 000.

The neural networks used by NeuroMetric's technology are multilayered. An input layer stores the input variables of the problem, an output layer reports the results, and a hidden layer aids in translating inputs into solutions. Additional hidden layers may be implemented to improve the network's convergence efficiency or classification efforts.

To enroll someone in the NeuroMetric system, the face is captured, the feature vec-

Texas Instruments, and Siemens, have developed verification algorithms for telephone applications [see "Speech," next page]. But it is smaller companies that have introduced products aimed at access control and computer sign-on.

A common question people ask about voice systems is, "What about impersonations?" This hazard is not serious, though, because the devices purposely focus on characteristics of speech other than those that people listen for and imitate. People form their speech patterns through a combination of physiological and behavioral factors that is impossible to duplicate.

Currently, voice verification is being used in access control for medium-security areas or for situations involving many people, as in offices and labs. Large corporations, including Martin Marietta, General Motors, and Hertz, are protecting computer facilities with this technology. Voice is also becoming fashionable for protecting dial-up computer links and terminal access. Five suppliers of home confinement systems, used to control the whereabouts of early parolees, employ voice verification to confirm that prisoners are at home.

There are two approaches to voice verification. One is using dedicated hardware and software at the point of access. The second approach is using personal computer host configurations that drive a network over regular phone lines. This approach handles general access control situations and costs over $1500 per door.

The PC-based systems, such as the one offered by Voice Strategies Inc., Troy, Mich., are currently more popular—understandably so, because the $20 000 to $40 000 cost of the base system can be evenly spread over a large number of doors, which themselves require nothing more expensive than a phone handset and locking mechanism. In telecommunications even this cost is eliminated because the phone is already present. Voice recognition is also being offered by such large companies as ITT, British Telecom, and NCR/AT&T. The latter offers an ATM with voice verification for smart card users.

A FAREWELL TO FORGERS. Signature dynamics, because of its promise for automating the job of verifying signatures in the financial community, has been one of the hottest areas of biometric development. Over 100 patents have been issued in this field, including several apiece to IBM, NCR, and Visa. Each of the companies that have commercial products uses a technique based on a slightly different principle and looks at a different aspect of the dynamic process of making a signature, such as the speed of writing and the order of strokes.

The key in signature recognition is to distinguish between its habitual parts and those that vary with almost every signing. Several identification devices also factor in the static image of the signature and some can capture that static image for records or reproduction. In fact, static signature capture is becoming a popular replacement for pen and paper in bank card, PC, and delivery service applications.

Generally, verification devices rely on wired pens, sensitive tablets, or both. Devices using the wired pens are the least expensive and the smallest but potentially the least durable. To date, though, the financial community has been slow in adopting automated signature verification methods for credit cards and checking account applications because bankers demand very low false-reject rates. Therefore, vendors have turned their attention to computer access and physical security.

By the late 1990s, signature systems are expected to be a very usual biometric in general public applications. Anywhere a signature is already used is a candidate for automated biometrics. The first biometric to retail for under $1000 was the Sign/On product, now owned by Checkmate Electronics Inc., Rosswell, Ga.

PERSONAL TYPING RHYTHMS. Keystroke dynamics, also known as typing rhythms, is one of the most eagerly awaited of all biometric technologies in the computer security arena. As the name implies, this method analyzes the way a user types at a terminal by monitoring the keyboard inputs 1000 times per second. The analogy is made to the days of telegraphy when operators would identify each other by recognizing "the fist of the sender."

The modern system has some similarities, most notably that the user does not realize he is being identified unless told. Also, the better the user is at typing, the easier it is to make the identification. Both the National Science Foundation, Washington, D.C., and the National Institute of Standards and Technology, Gaithersburg, Md., have conducted studies establishing that typing patterns are unique to the typist.

The advantages of keystroke dynamics in the computer environment are obvious. Neither enrollment nor verification disturbs the regular work flow because the user would be tapping the keys anyway. Since the input device is the existing keyboard, the technology costs less.

Keystroke dynamics may also come in the form of a plug-in board, built-in hardware and firmware, or software. All the same, technical difficulties abound in making the technology work as promised and a half-dozen efforts at commercial technology have failed. Differences in the physical characteristics of keyboards, even of the same brand, and communications protocol structures are thorny hurdles for developers.

TO PROBE FURTHER. Biometrics, along with smart cards and video identification systems, is covered in the *Personal Identification News* newsletter, whose annual subscription is $345. To become a subscriber, contact Warfel & Miller Publishing Co., 11619 Danville Dr., Rockville, MD 20852; 301-881-6668; fax, 301-881-2554. The company also publishes the *Advanced Card and Identification Technology Sourcebook*, which contains 50 pages of industry background and 350 company listings. It may be obtained for $125 from the same address.

Biometrics technology is presented annually at the CardTech/SecureTec Conference. This year's conference will be held April 10–13, in Crystal City, Va. For information, call 301-881-3383; fax, 301-881-2430.

The *Security Technology Newsletter* covers physical security and asset protection technology, and is available from Philips Busi-

tors extracted, and the neural network is trained on the features. Gray-scale facial images may be presented from live video or photographs via video camera, videotape, or videodisk. The neural network is repeatedly trained until it "learns" all the faces and consistently identifies every image. The system uses neural network clusters of 100–200 faces to build its face recognition database. If multiple clusters are required, they can be accessed sequentially or hierarchically. When faces are added to or deleted from the database, only the affected cluster must be retrained, which takes 3–5 minutes.

Faces that might fool a human observer, like those of identical twins, might also fool the NeuroMetric system. However, this system would be more objective than most people in picking up on minor differences between twins and in distinguishing persons with similar mannerisms but differing facial features. It would also be less influenced by changes in hair style or color, facial hair, glasses, and so on.

Another use of the NeuroMetric system is access control. Looking at each individual passing a security camera, the system can work in conjunction with a badge or personal identification system to confirm an identity. It can also be used in the law enforcement process, searching a mug shot database when a suspect is booked. Currently, subjects must stand still, facing the camera, but future generations are expected to be able to identify subjects under tougher conditions, for example, while walking past a camera checkpoint. NeuroMetric presently has one system installed at Sandia National Laboratory in Albuquerque, N.M., where it is being evaluated in an access control project for one of Sandia's clients. —*Tim Hutcheson*

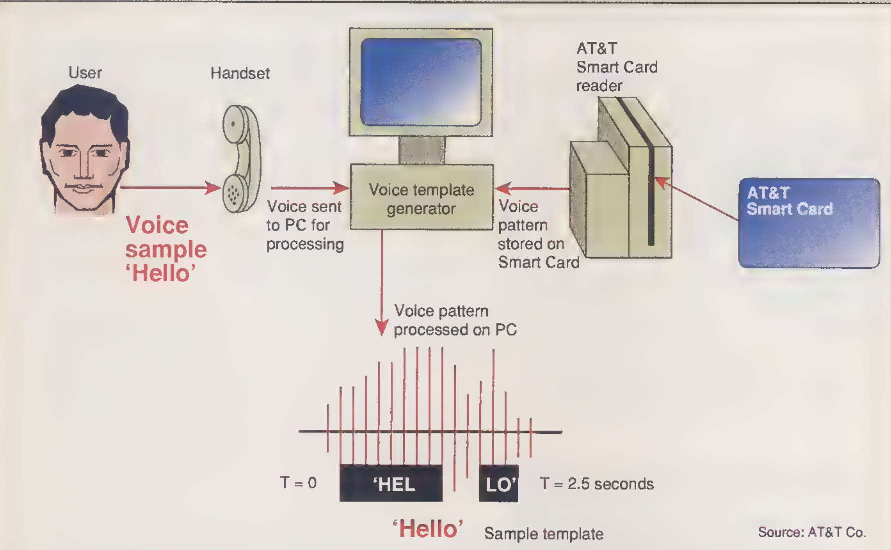
The author is president and chief science officer of NeuroMetric Vision Systems Inc., Pompano Beach, Fla., and also developer of its facial recognition technology. He holds a related patent in mathematics and engineering associated with prior work in pattern recognition. He previously was involved in image processing and robotics at Xynetics Inc. and managed technical groups at Machine Vision International, KLA Instruments, and International Imaging Systems.

SPEECH: just say the word

Perhaps the least invasive of the biometric recognition technologies and the most natural to use is speech matching. Speech, in effect, allows the remote identification of the complex musculature of the vocal system. One of the latest implementations of the technology is the recently demonstrated AT&T Smart Card used in an automatic teller system.

The AT&T prototype stores an individual's voice pattern on a memory card the size of a credit card. In brief, someone opening an account at a bank has to speak a selected two- or three-syllable word eight times. The word can be chosen by the user and belong to any language or dialect.

A system based on a 386 PC with a custom digital signal-processing board for a telephone connection digitizes the speech at 8 kHz, and automatically slices out the words by creating endpoints for each section of digital information. Samples of speech are taken every so many milliseconds (the number being set according to the application); the samples are quantified, then normalized to yield measures of about 20 variable parameters, including pitch, speed, energy density, and waveform.



In a speech-based identification system developed by AT&T Co., the user speaks a phrase, about a second long, into a handset. The phrase is digitized by a digital signal processor and shrunk by voice compression software, whereupon the pattern is stored on a personal computer and verified against test samples. Once approved by the voice template generator software, it is transmitted to a Smart Card reader and stored on a Smart Card.

Once the speech from each of the eight repetitions is converted to its spectral representation, overlapping samples of 30–50 ms are analyzed in this way. Then each series of waveforms that makes up one word is compared to the other repetitions, and a range chosen of acceptable waveforms, corresponding to a planned false acceptance level and false rejection level that can be set for each application. This range of waveforms occupies less than 700 bytes on a memory card.

Someone using the system inserts his or her Smart Card into a reader, in the same way magnetic-stripe cards are used in automatic teller machines (ATMs) today. The dynamic time-warping algorithm, using a sampling methodology that normalizes speech patterns to constant rate, volume, and pitch, is continuously scanning, adjusting for nervousness, shouting, or hoarseness due to illness. The user speaks the password, and the system compares the speech to the stored reference patterns. If it is within the prescribed range, the user is authorized.

Having a stored, portable voiceprint lets the recognition system operate without a central database, which could easily become unwieldy. Also, there are no limits to the number of speakers or languages.

But a couple of restrictions exist. People who are clearly matched anatomically, like family members who spent their years of language development in the same environment, could force a false acceptance, once the password is known. And if the speaker's own articulations vary greatly, as often happens in a nonnative language, the variations will cause a wide recognition range to be set that could include many people, both male and female. It appears that some sounds are more variable when articulated than others. Further research into this variability could improve the selection of passwords and so make voice recognition systems more accurate. Recent studies in acoustic theory, vocal cord characteristics, and neural network theory has certainly increased speech compression as well as speaker verification accuracy.

Another approach being studied as an alternative to the algorithms discussed is based on Hidden Markov Models, which consider the probability of state changes and allow the system to predict what the speaker is trying to say. This capability would be crucial for speaker-independent recognition. Storing voice templates on a card and receiving and processing voice information at a local device, such as an ATM, eliminates variations due to the telephone connection and types of telephones used, and obviates the need to do a database search. Using the technology over a telephone network would require the recognition algorithm to account for the network and telephone variations, a more difficult problem that is now being tested.

ATM applications have in fact been demonstrated and are ready to be implemented commercially. Other voice recognition systems from Verbex, Texas Instruments, Dragon Systems, Kurzweil Applied Intelligence, Digital Equipment, Sprint, and AT&T Long Distance Services are being used for telephone operator services, security, and automated access control.

—*Richard Mandelbaum*

The author is responsible for all development and forward-looking research for AT&T Smart Cards, Basking Ridge, N.J. Mandelbaum has been with AT&T Co. for 23 years, recently participating in the development of the Intelligent Vehicle Highway Systems (IVHS) strategic plan for Congress and leading IVHS standardization activities across the United States, Europe, and Japan. Within AT&T Bell Laboratories, Mandelbaum was responsible for developing AT&T's architecture for IVHS applications, including electronic toll collection, traffic management systems, and traveler information systems. He invented several new services within AT&T, including the original 900 service series, for which he holds two patents.

ness Information, 1201 Seven Locks Rd., Potomac, MD 20854; 301-424-3338; fax, 301-309-3847.

Security Management Magazine addresses some of the same security issues as the newsletter, and is available from the American Society for Industrial Security, 1655 North Fort Meyer Dr., Suite 1200, Arlington, VA 22209; fax, 703-243-4954. ◆

Ben Miller is editor and publisher of Personal Identification Newsletter (PIN) *in Rockville, Md., which covers technical developments and applications of biometrics, smart cards, and information security technologies. He is chairman of the annual CardTech/SecurTech Conference, which drew over 120 exhibitors and 2500 attendees to Washington, D.C., last spring. Miller is also a frequent speaker and writer on identification and card-based transaction systems and consults for corporations and government agencies throughout the world.*

Nuclear fusion advances

The last decade has seen advances in the shaping and confinement of plasmas, and in approaches to noninductive current drive

On the evening of Dec. 9, 1993, physicists and engineers at the Princeton Plasma Physics Laboratory in New Jersey did an experiment in which appreciable amounts of fusion power were produced for the first time in the United States. The event was part of the country's first experimental campaign to mix tritium with deuterium to fuel a fusion reactor.

The campaign is being conducted on the Tokamak Fusion Test Reactor (TFTR) at the national laboratory that is neighbor to Princeton University and serves as the principal U.S. fusion research facility. Tokamaks have emerged in the last decade as the overwhelmingly preferred approach to obtaining electricity from controlled nuclear fusion, and TFTR is the largest and most capable of the U.S. tokamaks. All are torus-shaped devices in which ionized gases are contained and compressed by magnetic fields.

A follow-on experiment at Princeton on Dec. 11 produced 6.1 MW of power in 0.75-second pulses, and by the time the tritium campaign ends later this year and decommissioning of TFTR begins, peak power of about 10 MW is expected. A crucial experimental issue in the campaign will be to determine whether the alpha particles—helium nuclei—generated in the deuterium-tritium reactions behave roughly as expected.

Previously, the Princeton tokamak and all other tokamaks in the world, with one notable exception, generated plasmas consisting of deuterium, deuterium and helium, or hydrogen. By comparison with deuterium-deuterium fuel, deuterium-tritium yields about 200 times as many fusion reactions, at the cost of producing more radioactive byproducts. The radioactive tritium is itself tricky to handle, and the far more energetic neutrons from the deuterium-tritium reactions irradiate reactor materials, which must be decontaminated and disposed of safely.

Because of the difficulties associated with tritium, the general strategy in fusion research has been to explore plasma behavior and confinement techniques using other fuels, on the assumption that fuels containing tritium would act similarly. But two years ago the Joint European Torus (JET) accelerated its schedule and got a jump on Princeton by conducting the first-ever tritium campaign. JET got big press in November 1991 with the announcement that it had produced 2 MW of fusion power in 2-second pulses.

Why was Europe the first to demonstrate fusion power? Tritium runs had been scheduled at Princeton for 1983 and then 1988 but were delayed, largely because of stretched-out budgets. Meanwhile, work at JET, which had started several years behind TFTR, was speeding up. Describing the situation, Tom Simonen of General Atomics in San Diego, Calif., likened it to being "in a race, [and] you see somebody gaining, but you've got [only] so much momentum, you're not going to win." The bottom line, says Simonen, is, "The JET people had the will. They wanted to do it, and they did it."

FUSION'S FIRST PEAK. Seen in perspective, the European and U.S. tritium campaigns represent the culmination of the big programs devoted to magnetic confinement fusion in the United States, western Europe, Japan, and Russia. Nor is this culmination just symbolic: the experiments have built on tangible advances that have been made in every important aspect of fusion technology since the 1973–74 energy crisis, which triggered the launch of the programs on a grand scale.

The experiments are also a culmination in that the tokamak approach has now swept the field, relegating to the sidelines all other approaches to the generation of fusion energy by means of magnetic confinement. Some work still is devoted to alternatives such as stellarators, an early concept for fusion energy pioneered at Princeton in the 1950s, but hardly anyone in the field expects the first demonstration reactor to be anything other than a tokamak.

Yet the Princeton and JET experiments also are a culmination in the sense of being a conclusion. Everywhere, the big national programs have come to be seen as too expensive, given the distant and still-receding time horizon for the demonstration and commercialization of tokamak fusion energy. In fact, a remarkable worldwide consensus has developed in the fusion and energy-policy communities to subordinate all national efforts to an international effort to design the next very large tokamak test reactor, the 1500-MW International Thermonuclear Experimental Reactor (ITER). That reactor may be the first to incorporate a breeding blanket to produce tritium.

FUSION QUANDARIES. Edward Teller, the father of uncontrolled thermonuclear energy (the H-bomb), once compared the effort to achieve controlled fusion by the magnetic confinement of plasmas to trying to contain a blob of jelly with rubber bands. The comparison is apt.

The underlying idea in tokamak fusion is to heat hydrogen or hydrogen plus helium isotopes to very high temperatures in a doughnut-shaped vacuum vessel, so that the atoms are stripped of their electrons, creating a plasma of positive ions and electrons. Toroidal and poloidal magnets external to the vacuum vessel generate magnetic field lines to hold the electrons and ions in the doughnut. A magnet in the core of the doughnut induces a current in the plasma by transformer action, generating the favorable tokamak magnetic configuration. The induced current, augmented by auxiliary radio-frequency or neutral beam heating, raises the plasma temperature to that required to achieve fusion reactions. The interaction of the various magnets causes the ions and electrons to course around the doughnut in helical orbits.

Given the evident challenges of confining unruly plasmas with magnetic strings, it has been no small matter to demonstrate the

William Sweet Contributing Editor

Defining terms

Aspect ratio: ratio of major (toroidal) radius to minor (poloidal) radius.

Beta: ratio of average plasma pressure to magnetic field pressure.

Bootstrap current: self-driven toroidal flow resulting from interplay of radial pressure gradient and viscous forces running parallel to the magnetic field.

Breakeven: Q (see below) exceeds 1.

Energy confinement time: the time during which energy is lost from plasma by cross-field transport and radiation.

Ignition: heating by alpha particles alone sufficiently to sustain a fusion reaction.

Kappa: in elliptical or D-shaped plasmas, ratio of vertical radius to horizontal radius.

Neutral beam: a beam of neutral particles; one of several means for heating the plasma.

Q: fusion power gain, or ratio of output to input power; needs to be 30 or so for a practical fusion reactor; depends mainly on triple product (see below).

Triple product: product of plasma density, energy confinement time, and ion temperature.

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plausibility of the idea with the experiments on either side of the Atlantic. But engineers scarcely need to be reminded that demonstrating the plausibility of something is not the same thing as demonstrating its doability, let alone its commercial doability. For that, many serious problems will need to be solved, and their solution is not a foregone conclusion. So fusion is still considered a basic research program and the construction of a commercial prototype reactor is not expected before the year 2040.

In the near term, the most pressing problems are connected with plasma "transport," that is, the outward drift of plasma across magnetic field lines; with the design of "divertors" to drain impurities and remove heat from the vacuum vessel; and with the irradiation of reactor materials by the 14-MeV neutrons from deuterium-tritium reactions.

Then there are the problems associated with the behavior of alpha particles, which is crucial to ignition scenarios, and which the Princeton tokamak will begin to address in the experiments just beginning. And there will be challenges connected with the design and testing of tritium breeding and heat transfer mechanisms, and the question of whether we are really stuck with tritium or whether it might be possible, with advances, to go over to a deuterium-deuterium or deuterium-helium 3 fuel regime.

FUSION MILESTONES. For usable deuterium-tritium fusion reactions even to begin, an average plasma temperature of about 50 million degrees, equivalent to a kinetic energy acquired at 4.5 keV, is required. Achievement of breakeven, the point where fusion power output exceeds input power, requires still higher temperatures, high ion densities and good energy confinement time, which is related to the rate at which energy is lost from the plasma by cross-field transport and radiation. The most widely cited measure of tokamak performance is the so-called "fusion triple product" of density, confinement time, and temperature [see illustration, below].

For ignition, the point where the fraction of alpha particles in the plasma is big enough to sustain plasma heating at fusion levels, a fusion triple product of 7×10^{21} particles per cubic meter $\times$ seconds $\times$ kiloelectronvolts might be required. The particle temperature would be equivalent to about 10 keV and the particle density times confinement time—the so-called Lawson criterion—to 0.7×10^{20} particles per cubic meter $\times$ seconds.

Another important measure of tokamak performance is beta, the ratio of plasma pressure to magnetic pressure in the vessel. Since the rate of energy production is proportional to the square of beta, and magnets represent a large fraction of tokamak costs, beta is a measure of the efficiency of energy production. Consequently, its value needs to be large enough to permit construction of an economically credible reactor. (One disadvantage of the tokamak design is that its beta values are low relative to competing designs.)

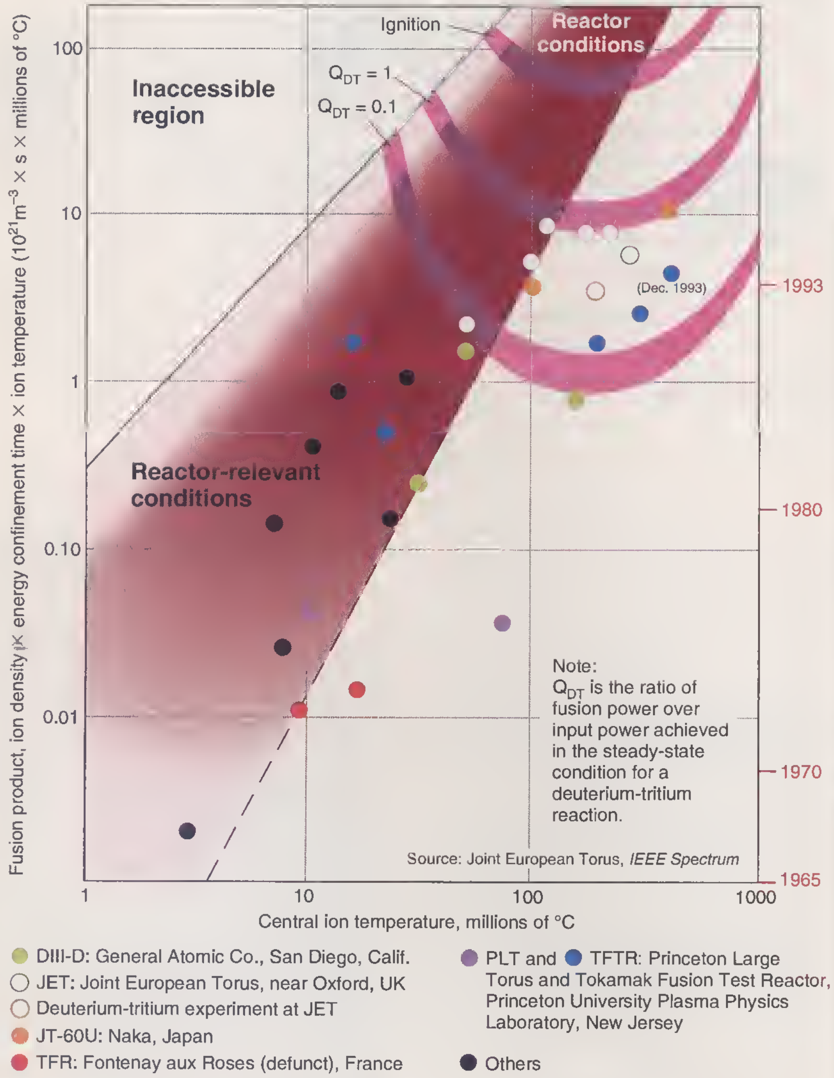
The astonishing thing is that the exacting requirements of fusion energy production have all been met in the last decade, albeit—and this is not an unimportant qualification—not all at the same time.

Since 1970, the central ion temperature in a tokamak has been increased eightyfold to 40 keV (roughly 450 million kelvin). Energy confinement time has increased two-hundredfold (and seventyfold for strongly heated plasmas). The triple product has increased more than six-thousandfold. Q, the ratio of output power to input power has risen by a factor of more than 1000, and beta has risen by a factor of 100.

While a beta value of about 5 percent has generally been taken to be a minimum requirement for self-sustaining fusion reactions, a value of more than 10 percent has been attained, by the General Atomics DIII-D tokamak reactor in San Diego.

Engineers of various descriptions have played about as big a role as plasma physicists in the last 10–15 years in fusion. Surveying those developments, Ron Davidson, the director of the Princeton lab, said that there have been "no major unpleasant surprises." What was unanticipated, he said, was "the amount of flexibility the big machines give you in terms of operating modes. What were thought to be the optimal combinations of temperature and pressure have turned out not always to be best."

PLASMA SHAPING. At present, JET and Japan's JT-60 have attained perhaps the best combination of confinement time, density, and temperature; but Princeton's unit and General Atomics' DIII-D have been producing results that are in the same ballpark, with each team issuing press releases with some frequency claiming the latest record. JT-60 currently claims a triple product of 11×10^{20} particles per cubic meter $\times$ seconds $\times$ kilo-



The evolution of research on nuclear fusion by magnetic confinement is measured in terms of the triple product—plasma density, energy confinement time, and ion temperature—and Q, the ratio of fusion power to input power. The recent (December 1993) experiment at the Tokamak Fusion Test Reactor at Princeton Plasma Physics Laboratory produced 6.1 MW of power, the highest so far for a deuterium-tritium reaction. The experiment had a triple product of 4.37 $\times$ 10^{21} particles per cubic meter $\times$ second $\times$ millions °C at 410 million °C, and a Q of about 0.5. A Q much higher than unity (about 30) must be reached to attain reactor conditions.

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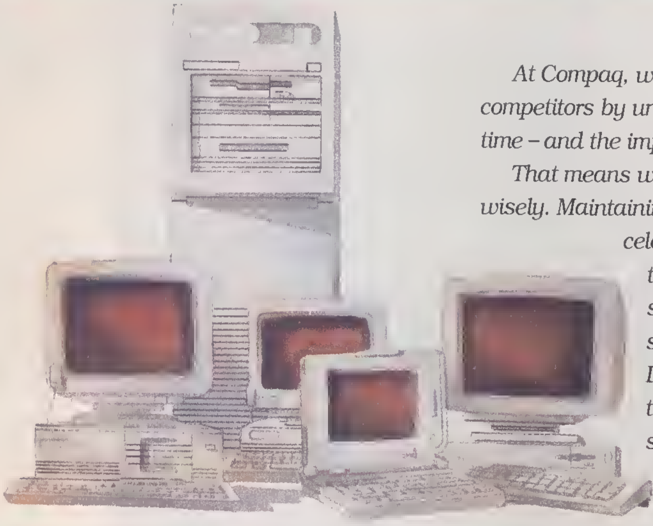

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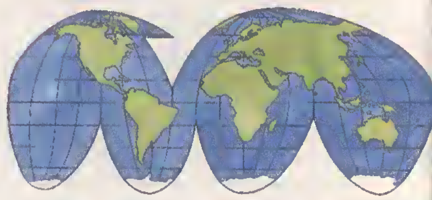

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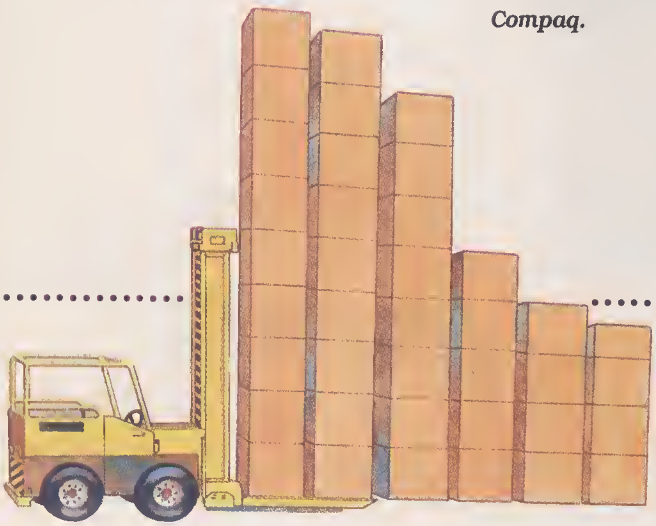

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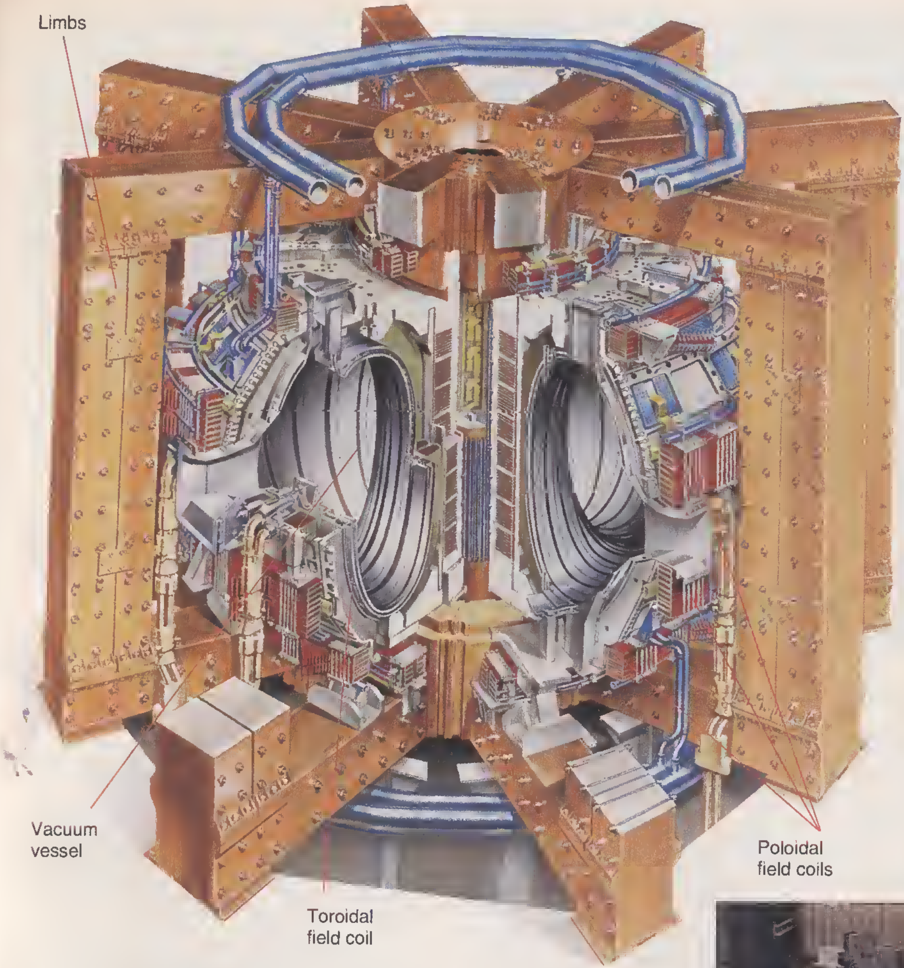
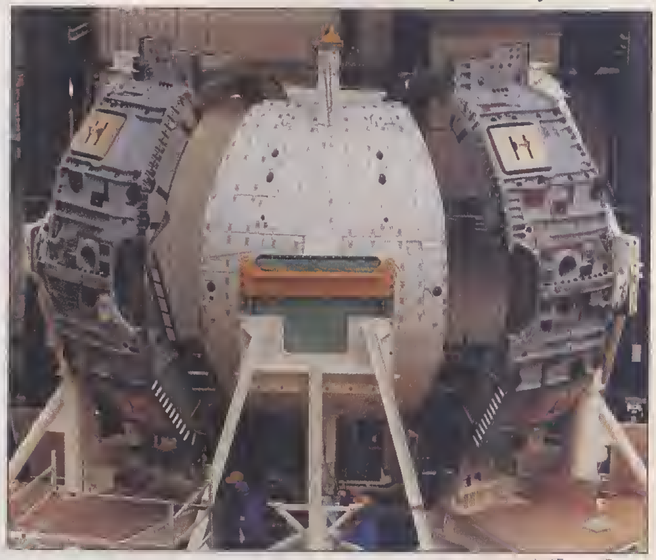


Even now the superiority of the D shape, like the H-mode, is not easily understood or explained. As a first approximation, joked Robert Goldston, the head of an important design team at Princeton, "it's nice to be elliptical." But it is by now well established both theoretically and experimentally that the D shape is a strong defense against the most virulent, large-scale plasma instabilities. The D shape also minimizes the tensile stress on the coil's winding, according to experts.

BOOTSTRAP CURRENT. Goldston is chief scientist for the Tokamak Physics Experiment (TPX), which has been designated the next major project after TFTR at the Princeton fusion lab. TPX is to be a "steady-state" or long-pulse reactor and will build on experience from France's Tore Supra in Cadarache, Japan's Trium-1M at Kyushu University, and Russia's T-15.

As described in a report to the U.S. Department of Energy by the Fusion Energy Advisory Committee in September 1992, "The scientific elements in the mission of TPX are aimed at the study of advanced tokamak operating regimes with high values of beta-poloidal and bootstrap current fraction, and with non-inductive plasma current drive and enhanced confinement modes during pulses lasting at least 1000 seconds."

The reason why present tokamaks operate with short pulses is, simply, that the direct current induced in the plasma by the cen-



Joint European Torus

The schematic diagram of the Joint European Torus, built in Abingdon near Oxford, Great Britain, in the early 1980s, shows the steel limbs of the transformer core, which weighs nearly 2700 tonnes; the eight-section vacuum vessel, in which the plasma is contained; a toroidal field coil, one of 32; and a poloidal field coil, one of six. The photo shows one of the vessel octants with shells that house toroidal field coils.

electronvolts, JET claims 9×10^{20}, DIII-D, 5×10^{20} and TFTR, 4×10^{20} m^{-3} s keV.

Significant tokamak experiments also are taking place elsewhere in the United States: at the Massachusetts Institute of Technology (MIT) on the newly built Alcator C-MOD; in Japan (besides at Naka, where JT-60 and other major devices are located), at Toki near Nagoya, the site of a stellarator; in France, at Cadarache; and in Germany at Garching, outside Munich, where both tokamaks and stellarators are being worked on.

The Asdex tokamak at Garching is credited with the discovery, for example, of the so-called "H-mode." This very useful phenomenon by now has been reproduced on close to a dozen tokamaks. It involves a transition in turbulence at the edge of the plasma, perhaps because of radial electric field shear or a thermal barrier, which permits confinement time that can be doubled or tripled.

One of the most important advances in plasma shaping came out of the series of experimental systems built by General Atomics, starting in the early 1960s, under the leadership of Tihiro Ohkawa. Depending on whom you talk to, it is either a story of brilliant pioneering science or a "weird history" that started with a "dumb idea" and ended with a really important discovery.

Ohkawa's tokamaks, dubbed the Doublets, consisted of a barbell-shaped plasma chamber. This was modified first to flatten the inner wall of the tube, and later to make the outer vacuum wall convex rather than concave. The result was an elongated or D-shaped plasma, the shape that has come to be the basis for all advanced tokamak designs, from JET and DIII-D to ITER.

Whatever else the story of the doublets may say, it certainly seems to show that progress in fusion still—even with all the work in computing, computation, and turbulence theory that has contributed so much to the field—depends heavily on good old engineering by trial and error. "Science often proceeds like this, by turning bad ideas into good ideas," noted Ian Hutchinson, the head of the Alcator project at MIT.

tral transformer magnet can be sustained only by a field that is growing ever stronger. Hence the cyclical operating regime, which subjects reactor elements to severe stresses and, let it be said, calls into question the economic plausibility of tokamak fusion.

Two things, mainly, make it possible now to visualize a reactor operating in much longer pulses: "bootstrap" current, a discovery of the current generation of big tokamaks; and innovative noninductive methods of plasma heating and drive.

The bootstrap phenomenon arises, Goldston explained, from the pressure gradient normally found in the plasma, such that pres-

sure decreases toward the periphery. In this configuration, the overlap of particle orbits from the high-pressure region (deep within the plasma) with orbits from the low-pressure edge region gives rise to a net positive toroidal current—thus the current "pulls itself up by its own bootstraps."

Scientists at Britain's Culham Laboratory at Abingdon, near Oxford, postulated bootstrap current in 1971, and its existence was experimentally confirmed unequivocally in 1986 at Princeton, which reported the results that year in *Physical Review Letters*—the premier physics journal for reporting major discoveries. Other leading labs quickly confirmed the results and significant bootstrap fractions—the proportion of total current due to the bootstrap effect—were soon achieved at JT-60, TFTR, and JET. Scientists at Naka and the University of California at Los Angeles independently proposed steady-state reactors with high poloidal beta and high bootstrap fraction.

According to Goldston, the discovery of bootstrap current came as a surprise in that it was not a deliberate result of the experiment in which it was found. Yet "if the theory were wrong in this, a lot of really fundamental things wouldn't be going on that are going on," he observed.

NONINDUCTIVE HEATING, CURRENT DRIVE. The bootstrap effect can be exploited in combination with methods of noninductive current drive to provide current profiles that presage greater stability and performance. The bootstrap current depends on density and temperature gradients, which tend to be strongest near the plasma edge. Noninductive current drive systems can be used to provide the remaining current in the plasma core.

The technique of injecting neutral ions was thoroughly explored at all the leading tokamaks during the late 1970s and early 1980s and can be considered well understood. JET, for example, is equipped with two neutral beam injectors and DIII-D with eight, each of the sets capable of supplying about 20 MW of heating; TFTR is equipped with 35 MW of neutral beam heating, and JT-60, with 40 MW.

During the last decade, the emphasis increasingly has been on exploration of radio frequency heating. At JET eight antennas in the vacuum vessel propagate waves in the range of 25–55 MHz and supply up to 22 MW of heating. At General Atomics (and other labs as well), a type of vacuum tube called a gyrotron is used to generate microwaves for electron cyclotron heating. Using 200-kW, 60-GHz systems on the DIII-D tokamak, the company has applied 1.7 MW of noninductive heating. JT-60's "lower hybrid" RF current drive system demonstrated 3.6 MA in 1993.

By using neutral beams for core current drive and RF or microwave heating for drive at the edge of the core, it is possible to obtain elaborate current profiles. Princeton's Goldston sees particular promise in "reverse shear regimes" obtained at the Tore Supra tokamak in Cadarache, France. Normally the degree to which the field lines are twisted as they spiral around the toroid is a function of the temperature profile, so that the twist is tighter toward the core and looser toward the edge. But that configuration of lines turns out to exacerbate instabilities. If, however, the edge current is tweaked to invert the normal pattern, better stability and performance result.

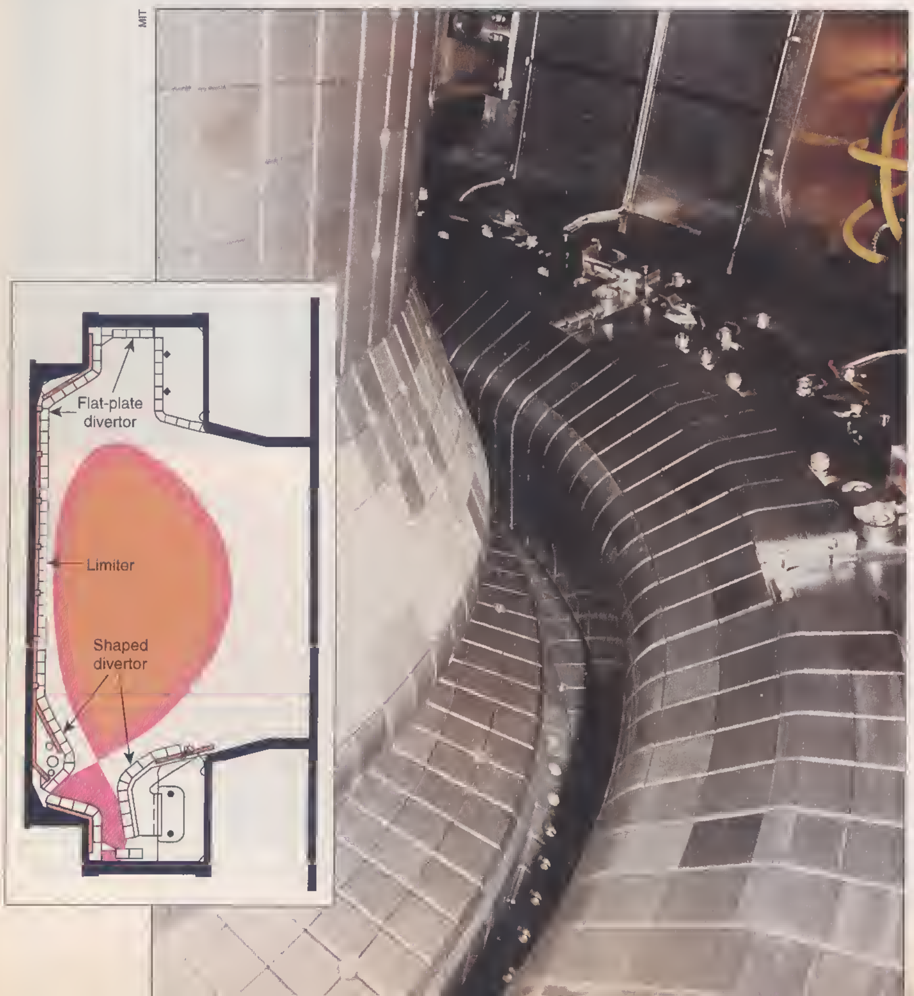
THE ROAD TO ITER. The U.S. fusion program is just emerging from a difficult period in which it faced a frontal challenge, reacted, and reorganized. Around 1988–89, the head of basic energy research at the Department of Energy, Robert Hunter, let it be known that in his opinion magnetic confinement fusion was not mature enough to proceed directly to ignition experiments. Hunter's credibility was somewhat undermined by complaints having to do with his involvement in inertial confinement fusion (the alternative approach to controlled fusion energy, in which tiny pellets of fusion fuel are bombarded with beams from high-power lasers). In due course he left the department, but the scuffle left a lasting imprint on the U.S. program.

Basically, the U.S. fusion community had to adjust to the fact that funding was and would remain about one-quarter the level once expected. So in order to sustain a meaningful program, the leading players had to scale back plans substantially and settle for second choices. Oak Ridge, Lawrence Livermore, and Los Alamos national labs are responsible for technology development but do not host major experiments, though combinations of them jointly manage TPX and the ITER home team.

Princeton had to give up plans for a larger tokamak, dubbed the Burning Plasma Experiment. Instead, recognizing that TFTR, with its circular torus, was becoming an obsolete machine, it settled for the rather short tritium run that has just commenced. In exchange Princeton was awarded the TPX project, which owed a lot to work done at other big labs, including MIT and General Atomics, on condition that it organize the project on a national basis. Although there has been some grumbling elsewhere in the fusion community, Princeton generally is felt to have kept its word. "It's made TPX a national effort more than anybody would have expected," said Simonen, the head of DIII-D at General Atomics.

MIT, which had been hoping for years to get funding from the Department of Energy for a superconducting tokamak, had to settle for yet another copper-coil machine. Alcator C-MOD, which first was conceived as a modification of Alcator C, ended up an all-new machine that was begun around 1987 and is just now being ramped up.

MIT

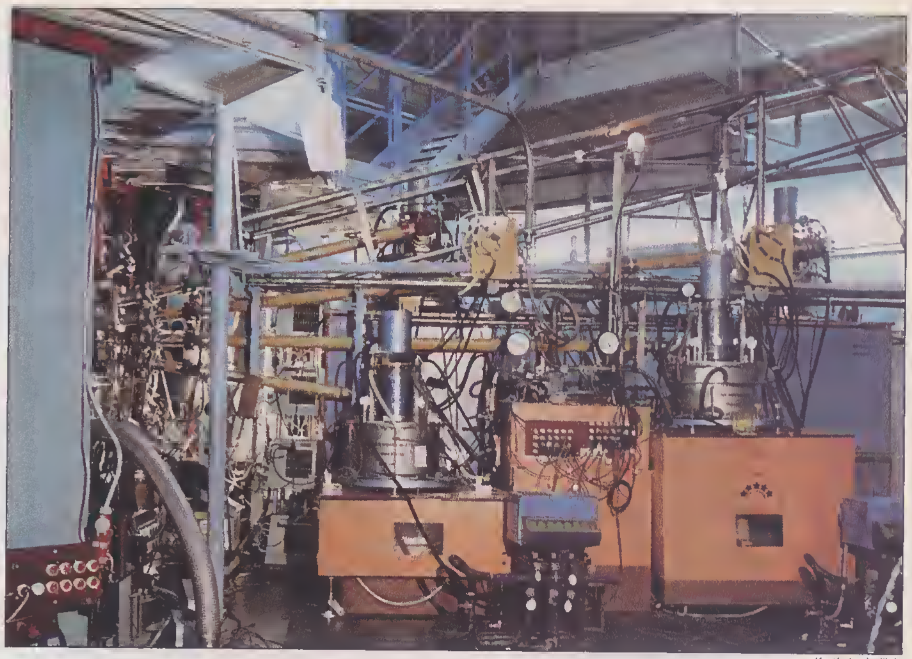


Divertor for the Massachusetts Institute of Technology's Alcator C-MOD, basically a gutter at the bottom of the vacuum vessel, employs a shaped baffle system to minimize recirculation of impurities. Ions diffuse across the separatrix [the x-shaped crossover point on the drawing] and hit the molybdenum plates at left and right so that impurities are generated outside the main plasma.

Relatively small, with a major radius of 0.67 meter and minor radius of 0.21 meter, its magnets will produce fields of around 9 teslas. That is about 50 percent greater than the strength of the magnets slated for the Superconducting Super Collider and comparable to those slated for Europe's competitor project, the Large Hadron Collider. The machine will produce a current of up to 3 MA, comparable to the Princeton tokamak's.

MIT's fusion program started in the 1960s under the wing of the institute's Francis Bitter High Field Magnet Laboratory, which until recently was the world's undisputed leader in ultra-strong magnets. Ever since, the MIT fusion program has emphasized high-field magnet technology; in fact, Alcator is an Italian acronym of *alto campo,* or high field.

Why Italian? According to Hutchinson, Alcator C-MOD head , the plasma theorist Bruno Coppi played an inspirational role in the program's early years, and Italian plasma physicists were heavily involved during the first decades. Hutchinson credits Alcator A with having established Alcator confinement scaling, the principle that energy confinement time increases with density. And he credits Alcator C with having been the first to achieve a high Lawson parameter (particle density multiplied by confinement time), albeit at a not very high temperature.


Kurchatov Institute

This gyrotron complex performs radio frequency heating of plasma at the T-10 tokamak, Kurchatov Institute, Moscow. Two of 11 gyrotrons can be seen in the foreground, sitting on beige boxes. The gyrotrons [blue] are embedded in superconducting magnets (stainless steel cylinders). Each gyrotron can provide heating at frequencies of 2 or 140 GHz, with pulse power of 500 kW and pulse duration of more than 1 second.

By a curious symmetry, MIT's Italian connection is matched at General Atomics by a Japanese link that started with Okhawa, the father of the Doublet series. The Japanese Atomic Energy Research Institute has put about $70 million in capital investment and staff pay into DIII-D—for all practical purposes the only money spent on magnetic confinement fusion in the United States that does not come from the U.S. government.

HERE COMES ITER. The high degree of cooperation that has been attained nationally and internationally is a conspicuous hallmark of the current scene in fusion and has been a precondition for the International Thermonuclear Experimental Reactor. The project is the result of an initiative that Mikhail Gorbachev took at the behest of Evgeny Velikhov, a well-known fusion physicist, in one of the early summit meetings with Ronald Reagan. ITER gradually won the support of the whole world fusion community, until last year the United States, Europe, Japan, and Russia agreed to launch the design phase. A joint central design team based at Naka, Garching, and San Diego is now at work on this phase.

The formal seat for ITER council meetings is Moscow; the council is headed by Velikhov, who has been a high-level adviser to the Soviet and Russian governments for many years. Management ("project integration") of the joint central design team is based in quarters up the road from General Atomics in San Diego. The selection of Paul-Henri Rebut, the former head of the Joint European Torus, to head the design team probably is a tribute not only to Europe's recent successes but even more to the somewhat daring elongated-plasma design that Rebut selected for the machine more than two decades ago, not to mention the excellence of the general engineering and good management.

ITER will be about two-and-a-half times the dimensions of JET, and might cost $7.5 billion to design and build over perhaps 13 years. Initially it will probably operate in a pulsed mode for 1000 seconds or more and is to achieve an ignited plasma.

All national efforts are coming to be seen as preparing the way, scientifically and technologically, for ITER. Thus, in the concluding tritium campaign at Princeton, according to the project's director Richard J. Hawryluk, a key issue will be the extent to which alpha particles are lost around the edges of the plasma. It emerged in the 1980s, he said, that alpha particles can decouple under certain equilibrium conditions, creating instabilities, as shown by supercomputer simulations.

Another big worry is whether optical-fiber and other diagnostic equipment is disrupted at the higher energies. Tokamaks are controlled primarily by fully automatic feedback loops from the diagnostics.

At the Joint European Torus, it is estimated that more than 100 person-years have gone into developing software and 50 person-years into the hardware for the integrated control and data acquisition systems.

IMPURITY CONTROL. Alan Gibson, JET deputy director, said that one reason the November 1991 tritium run was so short was that impurities from plasma-wall interactions rapidly built up, swamping the plasma. While use of beryllium in the walls has improved matters, the problem is far from solved. "It's a very difficult struggle," Gibson observed.

Simonen reports that at DIII-D the engineering of the wall—its smoothness, not the materials used as such—has been found to make a big difference with impurities. He likens the situation to playing basketball on an even versus a pocked floor.

Divertor technology is becoming more important in the control of impurities, as well as providing a mechanism for absorbing unwanted heat and removing helium ash. Divertor geometry is derived from the transition to elliptical or D-shaped plasmas: just beyond an X-point where field lines cross, plasma particles are guided to the divertor plates.

So, results from work on divertors at General Atomics and MIT will be another ITER input. DIII-D and JT-60 are equipped with open divertors; these are essentially slots located at the bottom of the torus and armored with graphite plates. JET is installing a semi-closed divertor, while Alcator C-MOD employs a shaped baffle system designed to prevent recirculation of impurities [see p. 34].

Design of a divertor for TPX will be especially challenging, Princeton's Goldston explained, because so far nobody has run a divertor for hundreds of seconds. A steady-state machine like TPX or long-pulse ITER will require active cooling of the divertor. The whole problem is particularly intractable because magnetic field lines can suddenly go chaotic in an "off-normal event," dumping heat onto the divertor plates a million times faster than normal.

One advantage of the stellerator design, noted Yuichi Takase, a Japanese-born scientist who has worked in the MIT fusion program for many years, is that all magnets are external to the vacuum vessel and no current

is induced in the plasma itself. Thus stellerators are immune to the "disruptions" in which tokamak current abruptly disappears.

One significant input in the ITER design is expected to come from Russia's Kurchatov Institute, which has been a leader in the development of microwave, or electron cyclotron, heating techniques. Several large tokamaks have been built at Kurchatov under Velikhov's direction.

The general idea in microwave heating is to inject microwaves at a frequency such that the electrons in the plasma are heated by cyclotron resonance; they in turn drive current and transfer heat to ions. The technique provides a steady current and highly precise localization of current drive and plasma heating.

Simonen reports that the Russian fusion science team has gone on working with "an incredible amount of dedication," despite horrendous general conditions.

Apparently the Russian team is relatively well supported. No doubt that privileged position owes something to Velikhov's eminence in the Soviet and Russian policy-making apparatus, rather more to what fusion energy could mean to an energy-intensive country like Russia, and maybe most of all to the seminal role that famous Russian scientists played in conceiving and demonstrating the tokamak concept. As is well known, Igor Tamm and Andrei Sakharov hatched the idea in the early 1950s, and it was first tested successfully by Lev Artsimovich and colleagues at the Kurchatov Institute in the early 1960s.

It is conceivable that tokamak fusion could pass every scientific, technological, and commercial test, and still fail in the world market

Nonetheless, given the desperate economic situation in the states of the former Soviet Union, it may not be possible for Russia to carry all the weight it once meant to shoulder in the ITER enterprise. In fact, Israeli fusion scientists have been exploring the possibility of joining in Russia's part of the operation.

Will tokamak fusion ever pan out? Time and again government, advisory, and corporate reports point out, basically correctly, that tokamaks will be immune to catastrophes that fission reactors can suffer—meltdowns of the kind seen at Three Mile Island or explosions caused by runaway nuclear reactions like the one at Chernobyl.

Just as regularly, fusion literature lauds fusion's potential as an unlimited energy source. The claim is both true and somewhat misleading. Current technologies for breeding tritium from lithium—which is not an unlimited resource—are very expensive and demanding. Of course the plan is to breed tritium in the tokamak blanket, much as plutonium is bred from uranium-238 in a fission breeder blanket. But this has yet to be done.

Then there are all the unpredictable issues associated with radioactive tritium and the material that would be irradiated by 14-MeV neutrons in a tokamak running on deuterium-tritium reactions. One of the main fusion investments recommended by the most recent U.S. advisory committees is a large system to test the effects of 14-MeV neutrons on a variety of construction materials. Such a reactor seems likely to be an international facility and may go to the runner-up country in the competition for siting ITER.

The fusion literature routinely expresses confidence that improved materials and processes will be found that minimize radioactivity. Tritium and most irradiated materials would admittedly have quite short half-lives (12 years and up) compared to the materials used and generated in fission reactors. Fusion advocates accordingly point out that radiation hazards associated with tokamak energy should be smaller than in our current nuclear economy.

According to estimates published in Germany's trade magazine for German physicists, a 1-GW tokamak reactor operating at 75 percent capacity would burn only 100 kg of tritium per year and would never contain more than a few kilograms of tritium at any one time. In normal operation, such a reactor might release 7.4×10^{14} becquerels of radioactivity into the environment per year, almost entirely in the form of tritiated water (HTO). A Candu nuclear (fission) power plant releases, by comparison, about 15×10^{14} Bq per year. The HTO releases from a fusion reactor would correspond to an exposure to a person living and eating year-round at the periphery of the plant of 10 microsieverts, or 1 mrem.

Even so, in the worst-case accident at a fusion reactor, such a person might be exposed to radiation at or above the internationally prescribed limit of 50 mSv.

Since it is easy for tritium to combine with hydrogen and water and since it crosses biological barriers relatively easily, its containment poses extremely tricky problems. A glance at Princeton's official literature on the tokamak fusion test reactor at Princeton conveys the magnitude and complexity of the Russian-doll-like tritium containment systems, which were designed in consultation with expert authorities from Savannah River (where tritium for U.S. hydrogen bombs has been produced) and from Canada, whose Candu reactors produce some tritium byproduct. The design of the TFTR systems, plans for the current tritium run, and emergency procedures have undergone intensive review, including much discussion with local community representatives.

POLITICAL IMPONDERABLES. It is reassuring that the people at Princeton and JET in England have managed to obtain the assent of local political authorities to their first tritium runs. But such hurdles may not always be overcome. Japan's JT-60, which in most respects is comparable to TFTR and JET, cannot conduct tritium experiments because it was agreed with local authorities, before construction began, that tritium would not be used in the machine. JT-60 scientists take the position that the case for tritium is only compelling in ignition operating regimes.

It is therefore at least conceivable that tokamak fusion could pass every scientific, technological, and commercial test, and still fail in the world market. The story of tokamak fusion could, in other words, be a repeat of what has happened with fission breeders. These, despite technical (if not yet commercial) successes, have been declared dead on arrival because of unappeasable public concerns about plutonium and deadly accidents.

Fusion advocates can take solace from the fact that such scenarios are so remote as to have almost no impact on current research plans. Some others, of course, still argue that the whole prospect of building a commercially attractive and publicly accepted fusion reactor is so far-fetched as not to be worth pursuing at all. But at least for the time being, those critics seem to have been defeated in all major countries that support fusion research. And so, in no small part because of the advances achieved with the first generation of big tokamaks, the road at least to ITER would seem to be clear.

TO PROBE FURTHER. Literature describing the major ongoing projects in fusion is available from the big laboratories such as the Joint European Torus in Abingdon, near Oxford, England; the Princeton Plasma Physics Laboratory in New Jersey; and General Atomics in San Diego, Calif. For ITER, see K. Tomabechi et al., "ITER Conceptual Design," *Nuclear Fusion* (June 1991), Vol. 31, no. 6, pp. 1135–1224, and "The ITER Tokamak Device: ITER Documentation Series," No. 25, International Atomic Energy Agency, Vienna, Austria, 1991.

The best sources for recent developments in U.S. policy regarding tokamak fusion are the Fusion Energy Advisory Committee's September 1992 "Report on Program Strategy for U.S. Magnetic Fusion Energy Research" and the Fusion Policy Advisory Committee's September 1990 "Final Report," both put out by the Office of Energy Research, Department of Energy, Washington, D.C.

Information on current technical and political developments may be obtained from Fusion Power Associates, the industrial lobby in Gaithersburg, Md.

For scientific background, see F. F. Chen's *Introduction to Plasma Physics and Controlled Fusion*, 2nd ed. (Pergamon Press, New York, 1984); J.A. Bittencourt's *Fundamentals of Plasma Physics* (Pergamon, Oxford, 1986); and I.E. Tamm and A.D. Sakharov, *Plasma Physics and the Problem of Controlled Thermonuclear Reactions*, edited by M.A. Leontovich (Pergamon, New York, 1961).

Environmental considerations are treated by J.P. Holdren et al, in "Report of the Senior Committee on Environmental Safety and Economic Aspects of Magnetic Fusion Energy," Lawrence Livermore National Laboratory report UCRL 53766, 1989. ◆

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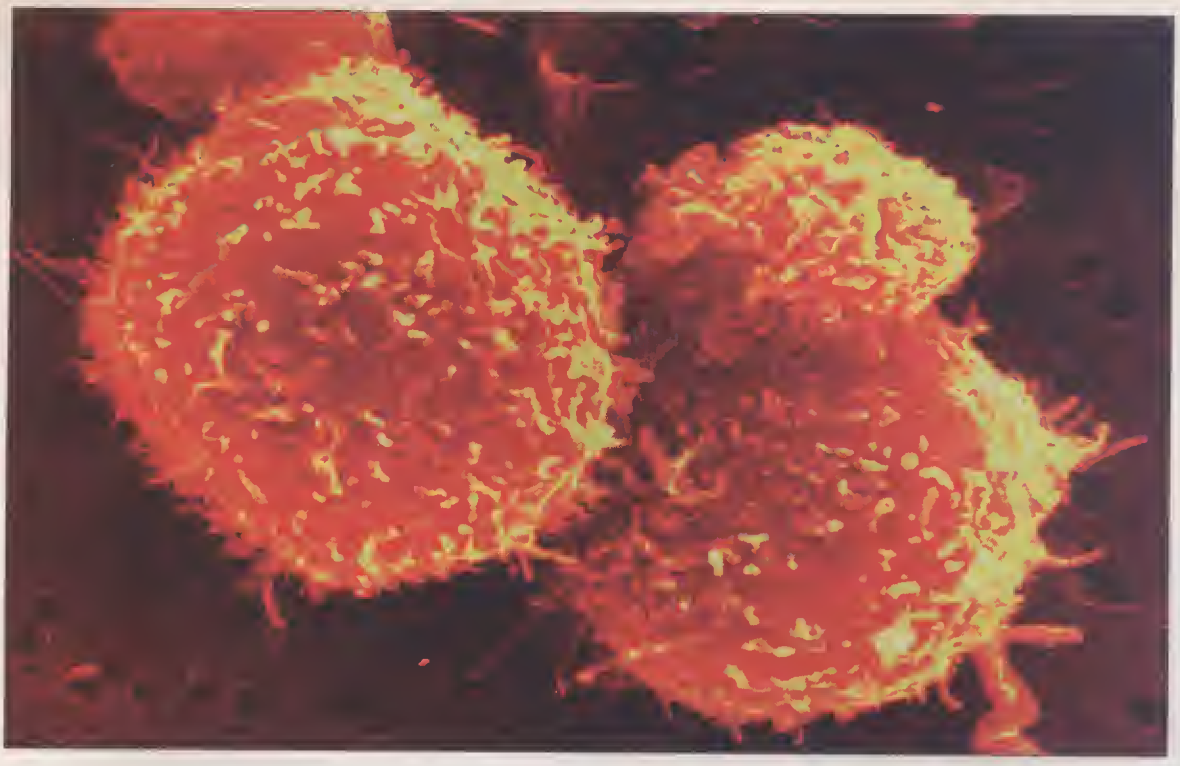


Electron microscope image of dust particles on a VLSI chip, rendered and enhanced with MATLAB. Data courtesy of MIT Microsystems Technology Labs.

Memory in the fast lane

The demand for higher-bandwidth memories in systems from multiprocessing to multimedia has designers pulling out all the stops

The mismatched bandwidths of fast processors and the slower memory chips they must employ are a problem of long standing. Processors now as always require more data per unit time than many standard memory chips have been designed to provide. In fact, signals encounter delays not only in the memory chip and package but also in the board traces and the connectors in the surrounding system.

Consequently, memory bandwidth adequate to an application's needs calls for the right combination of system architecture and processor and memory type. To help solve the problem in various applications, the manufacturers of memory ICs have responded with an array of fast innovative architectures, technologies, and hierarchies.

The largest bandwidth mismatch is between dynamic RAMs (DRAMs) and microprocessors [Fig. 1]. As the gap between them widens, it grows harder and more expensive to plug. The static RAM (SRAM), though, has generally managed to keep up with the processor speeds by resorting to wider buses, alternative technologies, and special interfaces. It has in any case an inherently shorter cycle time than a DRAM does, because the two have different types of memory cell. An SRAM stores data in a flip-flop consisting of normal logic transistors and is ready for the next read cycle as soon as one is complete. But the DRAM's capacitor cell is read by having current drained from it, so that time must be spent on writing the data back into the cell after a read access and precharging the bit lines before the next attempt to read the device.

However, the cost of a memory is determined in large part by the chip size. All other things being equal, SRAMs have about a quarter the capacity of DRAMs and therefore tend to cost about four times as much per bit. This economic disparity induced many suppliers in the 1980s to begin offering SRAMs tailored to a specific application, so that the devices enhanced system performance enough to justify a higher price.

Since the main justification for the existence of the DRAM is its lower cost, the focus in the DRAM industry is primarily on cost reduction. The chips' lower cost and higher density is what keeps them in demand. A faster DRAM or a cheaper SRAM could for some systems eliminate the expense of having to use both to obtain the advantages of both.

CACHE HIERARCHY. Meanwhile, the two types continue to coexist. Computer systems are for the most part based on an architecture called a cache hierarchy, in which a small SRAM is inserted between the microprocessor and a main memory made up of large banks of DRAMs [Fig. 2, far left]. Like any cache, the SRAM holds data that has a high probability of being the next to be wanted by the processor, so that less time is spent accessing the main memory's slower banks of DRAMs.

Most solutions to the bandwidth mismatch problem can be viewed as attempts to improve the performance of the system cache hierarchy, or to make it less expensive, or to eliminate the cache altogether. Logically enough, the design choices involve embedding the SRAM in the processor, in main memory, and between the processor and main memory, as well as more elaborate configurations [rest of Fig. 2].

In the first variation, integrating the SRAM into the processor transcends the bottleneck of the input and output buffers and enables the memory bus to be tailored to the wide width the processor generally needs. The first microprocessors with embedded instruction caches emerged in about 1987. The caches were small, consisting of 1 to 2 kilobytes of embedded SRAM. Most microprocessors today contain fairly sophisticated first-level SRAM caches, one each for data and instructions; they tend to be partially to fully associative. Currently, the most memory that can be cost-effectively embedded in a microprocessor chip is a scant 64 kB or so. For many high-performance systems, that means adding a second-level cache.

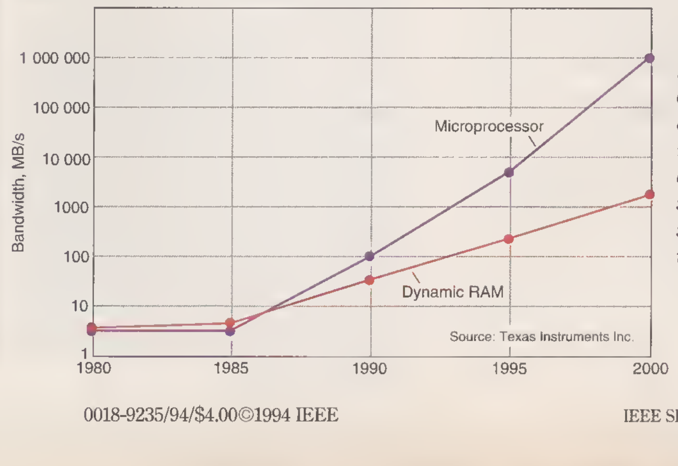
A second variation is to incorporate the SRAM into the DRAM, again unblocking performance through access to the wider internal bus of the DRAM. Examples are the video DRAM (VDRAM), which was introduced in the early '80s, and more recently two cache DRAMs: the EDRAM from Ramtron and the CDRAM from Mitsubishi ["A new era of fast dynamic RAMs," Fred Jones et al., *IEEE Spectrum*, October 1992, pp. 40–43]. Unfortunately, adding circuitry to the standard DRAM also adds to its cost as the chip and package size increase and as testing becomes more expensive.

A subset of this last case is to modify the output architecture of the DRAM, so that rapid bursts of data may issue from the wide internal DRAM bus without having to wait out the entire access cycle. This feature appears in the synchronous DRAM from the Joint Electron Devices Engineering Council (Jedec) and also in the Rambus DRAM and the Ramlink architectures.

RAPIDER RAM. There are many ways to speed up the RAM itself, including dividing up the internal architecture, switching to a different process, using wider outputs, and employing output modes that access data faster.

A divided architecture generally uses a tree-like hierarchical structure, in which lines with global access lead to lines with local access to specific sections of the RAM array. This shortens the datapath to the cells and reduces the capacitive load so that on both counts the device switches faster.

The price paid for a divided architecture is extra wire routing, entailing either more silicon or more layers of interconnects. Even



[1] The bandwidths of microprocessors and standard dynamic RAMs have been on the way up since 1980 as circuit speeds and data widths increase.

Betty Prince Memory Strategies International

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so, use of the architecture is on the increase along with the density and chip size of DRAMs and SRAMs. Typically, the memory array of a 16-Mb DRAM is laid out in four to eight major divisions and 32 subdivisions.

In fast SRAMs, extra speed may be gained by using alternative technologies to MOS, such as bipolar transistor-transistor logic (TTL) and emitter-coupled logic (ECL), or alternative materials to silicon, such as gallium arsenide and silicon-on-sapphire. An SRAM, for example, can be either completely bipolar or BiCMOS, in which the circuit elements requiring high drive current such as outputs and line drivers are bipolar and the rest of the circuits are CMOS. It is worth noting that MOS SRAMs also operate faster at a low temperature, as does CMOS logic, and speed gains in a liquid nitrogen environment have been reported.

The downside is that bipolar and BiCMOS technologies consume more power on standby and occupy a larger silicon area, raising costs. For gigahertz speeds where the expense of cooling techniques is not prohibitive, high-speed alternative-technology processors and memories are an option.

Alternative output modes access fast bursts of data from the wide internal structure of the RAMs. DRAM examples are the fast page mode, now popular, and older modes, like static column and nibble modes.

The different DRAM read operations are a good illustration of the various modes. When a row is selected by strobing in its address with the appropriate strobe pin, all the data on that row (page) appears on the sense amplifiers. In random access mode, only one column address is strobed in, and the corresponding data bits appear on the output pins. In a page mode read operation, the data from the selected row is held on the sense amplifiers while new column addresses are selected and strobed in. No time is spent on writing the information from the sense amplifiers back into the memory cells and precharging before another address in the same row can be accessed. In a 4-MB DRAM with 70-ns random access time, a page mode access typically takes 35 ns.

Static column mode is similar to page mode except that only the column address needs to be changed to obtain the new data and no strobe pulse is needed. Nibble mode—a predecessor of 4-bit-wide DRAMs—is no longer widely used. It grouped memory cells in fours so that whenever one of them was selected, 4 serial bits appeared on the single output. Hyperpage mode, also called extended data out (EDO), is a recent improvement to page mode timing. It adds an output control option that latches the old data on the output of the DRAM while a new access is begun. EDO helps to offset the delay caused by set-up-and-hold timing restrictions on page mode and can shorten the effective page mode cycle by 5 to 10 ns.

WIDER DATA. Matching the widths of a system's memory bus and a RAM's output will optimize the part's speed in the system by maximizing the amount of data transferred at one time. Byte-wide SRAMs have been paired with byte-wide buses for years, and 36-bit-wide SRAMs are already available for use with 32-bit microprocessors.

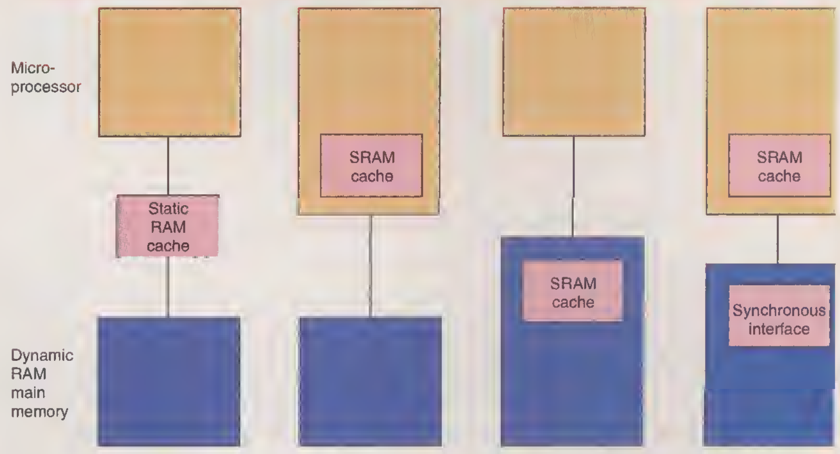
SRAMs moved to wider buses early because they are frequently used in applications in which a little memory must still match the width of the memory bus in the system. These are often battery-operated systems where the SRAM's low standby power is an advantage.

For example, consider a hand-held electronic diary that has an 8-bit bus and only 256 kB of memory. A single 256-kB byte-wide memory chip should suffice. Since it would be extravagant to add control overhead for a DRAM to support only one chip and since battery backup in such a system relies on low standby power dissipation, the most economical chip to use would be an SRAM.

The width of the DRAM, meanwhile, has not increased as fast as the memory bus width or even in fact as its own bit density. Since 1980 the most common DRAM width has increased from 1 bit to only 4 bits, although 16-bit-wide DRAMs are now available and wider parts are forecast for the future [Fig. 3]. However, personal computers normally use single-in-line memory modules (SIMMs) for main memory. These are small printed-circuit boards stocked with multiple DRAMs arranged in parallel and used like individual components, being fitted vertically into the main printed-circuit board. Their widths range from 32 to 144 bits in various applications and match the memory width to the PC's memory bus width.

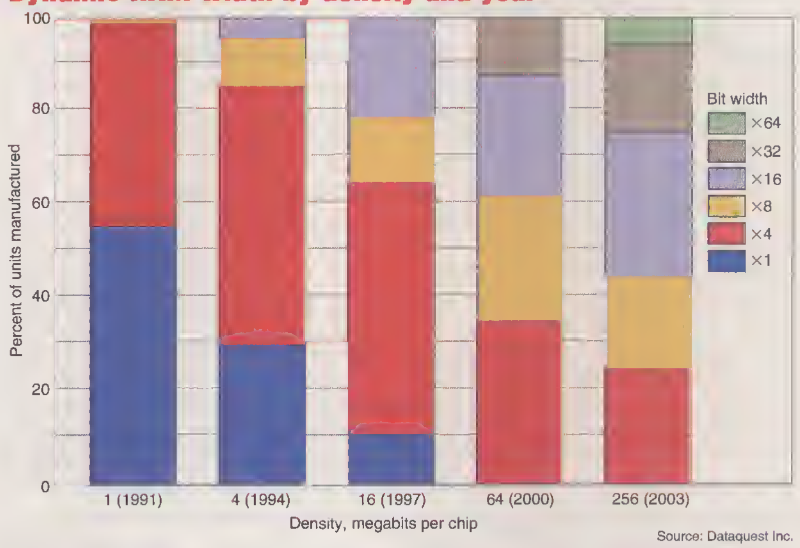
In cases where the processor runs at twice the frequency of the DRAM, a match can be made by doubling the width of the memory bus on the memory module and interleav-

Computer memory hierarchies for high-speed systems



[2] From left to right, the traditional memory hierarchy has a fast static RAM cache between the processor and the main memory. Performance is gained by incorporating the cache into the processor or the main memory. A first-level cache in the processing unit and synchronous interface on the dynamic RAM provide higher bandwidth from the main memory.

Dynamic RAM width by density and year



[3] Over the years, the trend in dynamic RAM I/O organizations has been toward wider data widths. Parts as wide as 64 bits should be available by the year 2003.

ing the two banks of data. This maneuver is most useful in larger systems that require the extra memory. But if the granularities of the available memories exceed the amount of system memory required, interleaving can increase the cost of the system memory.

Granularity—the minimum increment of memory that may be added to a system—can be troublesome since, as noted earlier, the output widths of the DRAMs have not been increasing at the same pace as their bit density. The granularity increases as the width of the memory becomes narrower with respect to the memory bus. An illustration is a system with a 16-bit-wide bus that uses 4-Mb DRAMs. If the chips are organized as 1 Mb × 4 bits, then it takes four of them to fill out the 16-bit bus with a minimum granularity of 4 × 4 Mb = 2 MB of memory. If, however, the organization is 4 Mb × 1, then 16 of them are needed to fill out a 16-bit bus with a minimum granularity of 16 × 4 Mb = 8 MB of memory.

APPLICATION-SPECIFIC DRAMs. Specialized memory architectures match the RAM output to the application so that the effective speed is maximized. An early example of this approach to bandwidth matching is the video DRAM (VDRAM), which after processing the data feeds it very rapidly to a video display. The VDRAM has two access ports, one random and one serial. The random port interfaces with the processor or controller. The serial one is fed data from a 256- or 512-bit register, which is loaded by an internal transfer from the sense amplifiers. The register data flows out through the port at the speed required by the video display.

The VDRAM is excellent for very fast graphics manipulation in many high-end PCs, low-end workstations, and other applications that require great performance but only modest memory. In these circumstances, it would be impractical to boost speed by interleaving banks of standard DRAMs.

The disadvantage of the VDRAM is the larger chip and package size. The serial register needs space and increases the cost. The package expands to cope with the added control pins and serial port I/O pins, which require more space on the printed-circuit board. For example, a 1-Mb DRAM organized as 256 × 4 has 20 pins, including nine address pins and four multiplexed I/O pins, whereas a 1-Mb 256 × 4 multiport VDRAM needs a 28-pin package to accommodate four serial I/O and four control pins. The testing procedure is also more complex for the VDRAM, increasing the cost of manufacturing the memory.

An alternative architecture that is also used in video applications is the frame buffer DRAM, which has interfaces only in the display channel. Because this DRAM has a serial I/O structure, the many address pins required by random access memory are superfluous. A smaller package can be used, and in theory, the frame memory can cost less than a standard DRAM. Consider the TMS4C1050B, a 1-Mb 256 × 4 field memory from Texas Instruments Inc., Dallas. It dispenses with the nine address pins of the 1-Mb DRAM but acquires four pins to demultiplex the I/O ports. The net result is only 16 pins, compared with the 20 on the 1-Mb DRAM (plus one extra control pin) and the 28 pins on the multiport VDRAM. Conversely, the loss of random access capability restricts the frame buffer's applications.

SYNCHRONOUS MEMORIES. A class of fast architecture memory that is becoming widely available is the synchronous, or self-timed, RAM. Synchronous SRAMs have been around for some time and are made by Hitachi, Micron Technology, Integrated Devices Technology (IDT), and Cypress Semiconductor among others. Synchronous DRAMs are being widely discussed, and a few early versions have appeared on the market [*Spectrum*, October 1992, pp. 44–48]. These are the cache DRAM from Mitsubishi, the Rambus DRAM from NEC, Fujitsu, and Toshiba, and the Jedec standard synchronous DRAM that has been announced by at least nine vendors, including NEC, Fujitsu, Toshiba, Texas Instruments, Hitachi, Samsung, Mitsubishi, Micron Technology, and Oki.

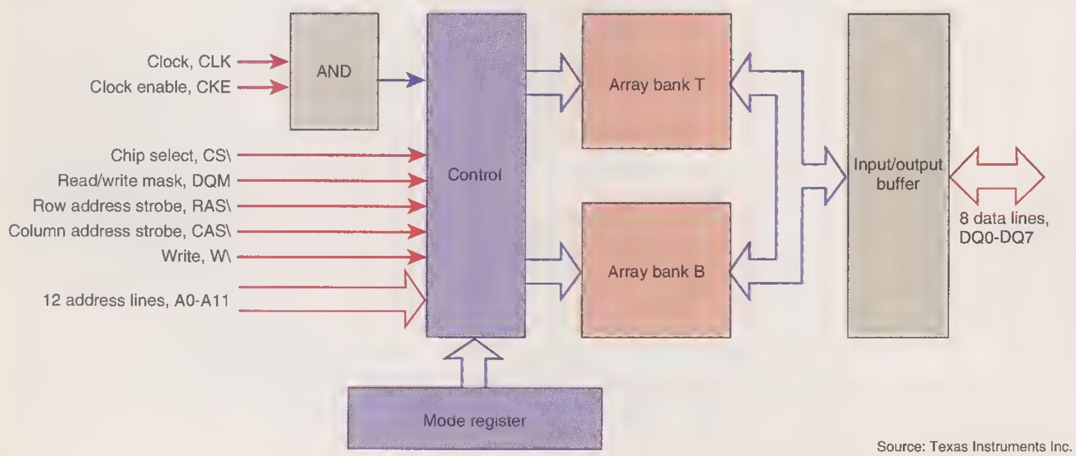
In synchronous memories, dual latches called registers guard some or all the inputs and outputs. They serve to shorten or get rid of wait states in a system with a fast microprocessor. (Wait states are the extra cycles the processor spends waiting for the data it has requested from the RAM.) A synchronous RAM can have the input addresses latched into it in one cycle by the microprocessor, which is then freed to perform other tasks until, a known number of cycles later, the memory has the required data ready on the output. While the intrinsic speed of the RAM has not increased, its effective speed in the system is greater because the processor need not idly wait for the data to come out of the RAM.

Further augmenting the speed of the Jedec standard synchronous DRAM and the Rambus DRAM is the use of multiple banks on a single memory chip. Random access is faster when one bank may be precharged (or refreshed) while the other is being accessed. Multiple rows on a Jedec synchronous DRAM can be simultaneously open, and accesses of the two banks can be interleaved on the chip [Fig. 4]. A multiplicity of internal banks also helps small fast systems with the memory granularity problem. Speed can be increased by interleaving the banks on one chip, saving the expense of memory required to interleave multiple banks in the system.

Both the synchronous DRAMs and the synchronous SRAMs feature burst mode accesses that are compatible with the Intel 80486 and later generations of processors. These are swift accesses to a modicum of data following an initial access at normal memory speed. The addresses of the subsequent bits of data in the burst are generated automatically by the RAM.

Like page mode, these burst mode accesses exploit the fact that the RAM's internal bus is wider than the external bus. Accordingly, all the data from a series of burst mode addresses can be fetched to the RAM outputs from its databank upon the entry of the first address. This data can then be fed out of the RAM at the clock speed.

Interestingly, the system clock edge is the only timing strobe that must be provided by the system to a synchronous memory. The need to propagate multiple timing strobes around the printed-circuit board or module is therefore lessened. In the synchronous DRAM, all internal strobes required for its operation are referenced to this external clock. At the rising edge of the system clock, a mode register on the synchronous DRAM



[4] The functional block diagram of a two-bank synchronous dynamic RAM contains clock and clock-enable features. The new read/write mask pin (DQM), when high, masks write data. The mode register stores the information for the current cycle. The two-bank architecture makes it possible either to access one bank while precharging the other, or keep both active (which enhances speed) by interleaving bank accesses.

is sampled. The mode register is set to indicate the burst length, burst type, latency mode, and combination of commands for the operation requested. A simplified truth table of commands is shown in Fig. 5.

SYSTEMS AFFECT SPEED. Also of concern are the electrical characteristics of the RAM I/O gates, not to mention the areas beyond: the transmission lines, the pinouts and packages, and system timing tolerances.

The characteristics of RAM inputs and outputs are standardized since they must interface with other components in the system. Interfaces capable of higher than standard speeds are not new. Historically the 5-V TTL interface was faster than the CMOS interface in that it limited the output swing of the circuit. The 3.3-V low-voltage TTL (LVTTL) interface characteristics are the same as those of TTL, but the gain over CMOS is not so great as with 5-V TTL since the full-rail swing of CMOS is less at the lower operating voltage. For higher speed at 3.3 V, a smaller swing interface is needed; and several have been standardized, including Gunning transceiver logic (GTL) and center-tap-terminated (CTT) logic by Jedec; backplane transceiver logic (BTL), by the Futurebus committee; and a low-swing differential interface by the IEEE RamLink standards committee (IEEE 1596.4). Rambus also uses a proprietary low-swing interface [*Spectrum*, October 1992, pp. 50–53].

At clock frequencies beyond 66 MHz or so, the system's transmission line characteristics come into play. In all the high-speed interfaces mentioned, the answer is a reference voltage level supplied either on the RAM or externally, plus careful design of the output buffers. Their design needs to take into account whether the RAM is operating in a point-to-point environment or on a parallel bus, and whether the bus is terminated or not. One part designed for these different system environments is a synchronous ×36-organized BiCMOS SRAM with a ×36 organization from Motorola Inc., Austin, Texas. It has GTL-type output buffer options for point-to-point operation, as well as parallel terminated and unterminated buses.

Another method used to gain speed is to access the memory on both the rising and falling edge of the clock pulse. This requires more control of the clock, but appears to be necessary to attain speeds over 200 MHz. This differential clock technique is used in both the Rambus and Ramlink schemes to reach 500 MHz and beyond.

The pinout and the package also affect the speed of the part. For the synchronous SRAM, Jedec has standardized a revolutionary pinout designed to minimize the self-inductance of the package lead frame. An increase in the number and placement of power and ground pins reduces the ground bounce that slows down the device when wide outputs switch. The Jedec standard synchronous DRAM also uses a larger number of power and ground pins than usual.

Smaller packages, such as the thin small-outline package II (TSOPII) with its lower lead inductance, are also being used to improve speed for the synchronous DRAM. Small vertical packages are used for the Rambus, and fast SRAMs are being housed in new packages such as thin quad-flat packs and even pin grid arrays.

Simulation helps with another important factor: the timing tolerances of the various parts in a system running at 100 MHz. At both the system and the component level, simulation tools help model the components in the transmission line environment of the system. Over the past year, the process of developing models of the system components as well as the whole system has become an integral part of designing high-speed components such as the synchronous DRAM into systems.

SOME SRAM CACHE IDEAS. In the SRAM area, various architectures of cache SRAMs all increase the bandwidth between processor and main memory by holding small amounts of frequently requested data in a small fast SRAM near the processor. The tradeoff here is the cost of the fast SRAM due both to its elaborate, four- or six-transistor memory cell and to the divided architectures required to obtain high speed.

Since the effective speed of the processor can be multiplied many times if the SRAM cache hit rate can be improved, architectural changes are being made to the older, direct-mapped SRAM caches, in which each address corresponds to an address in main memory. Thus, a larger cache has a higher hit rate.

The newer associative cache stores the same bit of data at several locations. In practice, fully associative caches are seldom used since the controllers are very complex and SRAM content-addressable memories (CAMs) are extremely expensive. However, much of the benefit from the increased hit rate of an associative cache can be obtained instead from a two- or four-way partitioning of the memory, a layout that requires a far simpler controller. In a two-way set-associative cache, for example, the data can be stored at either of two possible locations in the cache.

While most fast processors today find a direct-mapped cache adequate, future high-speed processors may seek a more complex cache organization, to avoid losing an even higher number of cycles during a cache miss.

For sure, processor speeds are not stagnating. Two further demands on the SRAM cache are already in the wings. New processors such as the Intel Pentium or the Texas Instruments Multi Video Processor (MVP) contain multiple execution units. And systems with multiple external processors are becoming more common. With a plurality of processors attempting to access the cache at ever higher data rates, the bandwidth demand on the memory can only grow.

TO PROBE FURTHER. Betty Prince's textbook, *Semiconductor Memories* (John Wiley and Sons, 1991), discusses the subject thoroughly from its beginnings to the latest developments. S. Przybylski's *Cache and Memory Hierarchy Design: A Performance-Directed Approach* (Morgan Kaufman, 1990) is an excellent reference on cache memory.

A number of recent articles describe the latest approaches to memory design; among them are *IEEE Spectrum*'s "Special report on high-speed DRAMs," October 1992; pp. 34–57; "Cache Architectures Under Pressure to Match CPU Performance," by Don Tuite, p. 91, and Charlie Hochstedler's "Cost-Effective PC Cache Memory Computer Design," p. 93, both in *Computer Design*, March 1993; and "High Speed Bus Interfaces," by Richard A. Quinnell, *Electronic Design News*, Sept. 30, 1993, p. 42.

Brett Williams's "Synchronous DRAMs: Designing to the JEDEC Standard," *Micron Design Line*, Vol. 2, Issue 2, 1993, is a clear guide to this new architecture. The Texas Instruments approach is discussed in W. Vogley's application note "The Synchronous DRAM," Sept. 29, 1993. ◆

Betty Prince is president of Memory Strategies International, a semiconductor memory services company. She has spent 22 years in the semiconductor industry, having held management positions in development engineering, marketing, and operations at Motorola, NV Philips, and most recently Texas Instruments. She is the author of two books on memories, and is coauthor of an upcoming book on embedded memories (IEEE Press). She has been involved in the EIA Jedec JC42 memory standards committee since 1982, and is currently a U.S. national delegate to the IEC SC47A WG3 International Memory Standards Committee.

The Jedec synchronous dynamic RAM: a simplified command truth table

Command	Chip select, CS\	Address strobes: Row, RAS\	Address strobes: Column, CAS\	Write enable, W\
Mode register (set or read)	L	L	L	L
Row address entry/bank activate	L	L	H	H
Column address entry and write	L	H	L	L
Column address entry and read	L	H	L	H
Bank deactivate/precharge	L	L	H	L
Command inhibit	H	X	X	X
Burst stop	L	H	H	L
Self-refresh	L	L	L	H

Jedec = Joint Electron Devices Engineering Council; L=logic low; H=logic high; X=don't care.

ATM knits voice, data on any net

Asynchronous transfer mode looks like the most practical communications choice for the talkative, data-heavy future

The hottest topic in the communications industry is asynchronous transfer mode, or ATM. After hiding out for several years in standards committees around the world, the technology is grabbing headlines in every periodical in the field. The reason: it is the first technology to merge voice and data communications into a common format that is equally and equitably inefficient for both. The deal is better than it sounds. It is in fact a tremendous improvement over past approaches, which were optimized for one type of traffic and provided only marginal service for the other.

Since its inception, the worldwide telephone network has been continually improved exclusively for one service—voice. Datacomm users, therefore, have been forced to use a network that is less and less suited to their needs, one designed to provide a low-bandwidth connection for a period of time measured in minutes or even hours.

In the early days of data communications, modems could perform well enough over such a network; but mushrooming data traffic has pushed the devices to their limits. Increasingly, data communications need a very wideband connection (tens of megahertz) for mere milliseconds at a time.

ATM is the first technology to provide a common format for bursts of high-speed data and the ebb and flow of the typical voice phone call. In addition, the format it uses—the cell—is equally at home in any network, local- or wide-area, public or private.

Hence the excitement: not only does ATM finally provide a means for integrating voice, video, and data, but it also knits local- and wide-area networks and services into a seamless whole.

ATM TECHNOLOGY. Asynchronous transfer mode is one of the general class of digital packet-switching technologies that relay and route traffic by means of an address contained within the packet. Unlike more familiar packet technologies, such as X.25 or frame relay, ATM uses very short, fixed-length packets, called cells [Fig. 1].

ATM cells are 53 bytes long. They consist of a 5-byte header (containing the address) and a 48-byte information field. Frame relay, by contrast, uses a 2- or 4-byte header and a variable-length information field. Frame relay is so named because it transfers, or relays, frames of user data, which can range from 64 to over 1500 bytes in length.

What makes packet technologies attractive for data traffic is that they exploit communication channels much more efficiently than do the synchronous transfer mode (STM) technologies commonly used to transmit digitized voice. The common T-carrier systems and other STM services are not routed by address, but over dedicated physical paths established either when a dialed call is set up or when a private line is installed ("provisioned," in telecommunications industry parlance).

Voice traffic would suffer if the words arrived in bunches with irregular gaps in between. Hence, service providers ensure regular delivery by transferring the information synchronously. That is, a time-division multiplexing system like T1 is based on a period of time, called a frame, which is divided equally into as many time slots as there are voice channels—24 in the case of T1. The time slots are multiplexed together with a frame bit to form the T1 signal. Each time slot is synchronized to the frame bit (hence the term synchronous transfer mode).

With each time slot representing one voice call, that call's digitized voice traffic is guaranteed access to the assigned slot for as long as the call lasts. Instead of addresses, STM technologies identify data by its position within a frame. Therefore time slots within an STM frame cannot be shared among calls. Even when a talker is silent, his or her time slot cannot be grabbed by another user.

For voice service, this is no great loss. Being able to grab extra time slots would not improve voice communications very much. But, for data transfer, it could be very useful. Since data does not require periodic transfers like voice, a data circuit could utilize unused time slots whenever they appeared.

Packet and cell technologies gain efficiency for data transfer by giving users access to the entire communication channel when they need it, for as long as they need it. Of course, if the channel is in use, a new user may have to wait to gain access. But for data this delay is not a problem; it is compensated for by the fact that when the user does access the channel described above, there is 24 times the bandwidth available.

Clearly, by giving users access to the whole channel at random intervals for random lengths of time, packet-switched technologies give up the possibility of identifying data on the basis of its particular time slot within a frame. Hence the need for a header containing an address representing the destination of the message. The message is identified by its address or label, and for this reason, ATM is sometimes referred to as label multiplexing as opposed to position multiplexing used by STM.

The 53-byte length of the ATM cell is a compromise designed to make ATM useful for data as well as voice, video, and other real-time traffic that cannot tolerate randomly varying transmission intervals and delays. Pure data sources can produce very long messages—up to 64 kilobytes in many cases. By forcing such messages to be segmented into short cells, ATM ensures that traffic like voice and video can be given priority and need never wait more than one 53-byte cell time (3 μs at a 155-Mb/s data rate) before it can gain access to a communication channel. With frame-based technologies, the wait would be a random interval—possibly several milliseconds in length.

Chopping a long data frame into 48-byte pieces and adding a significant amount of overhead in the form of the 5-byte header reduces the efficiency of ATM for pure data transfer purposes, but enables the same technology to be used for any kind of service.

Defining terms

Asynchronous: not derived from the same clock, therefore not having a fixed timing relationship.

Connection-oriented service: a type of service in which, for any given call or session, information traverses only one path from sender to receiver.

Connectionless service: a type of service in which no particular path is established for the transfer of information.

Isochronous: carrying embedded timing information or dependent on uniform timing—digitized voice, for example.

Sonet: synchronous optical network, a (growing) body of standards that describes all aspects of handling digital traffic over optical-fiber facilities in the public network.

Synchronous: derived from the same clock, therefore having a fixed timing relationship.

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This includes not just today's voice services but future multimedia applications as well. This flexibility is simply not available from any other service today.

OTHER BENEFITS. ATM has generated a lot of enthusiasm in a very short period of time because bandwidth efficiency and multi-service capabilities are far from being its only advantages. The many others include scalability and flexibility.

ATM is a scalable technology. Other digital communications technologies usually tie rates and formats firmly together. Ethernet is a 10-Mb/s technology by definition; T1 is a 1.544-Mb/s standard, and so forth. The ATM standard describes only the 53-byte cell format, without specifying rates, framing, or physical bearers. Thus many different systems, such as local-area networks (LANs), switches, and public networks, can use the same format at whatever rate is convenient or necessary. ATM cells can move with equal ease at common LAN speeds like 100 Mb/s and at public network speeds such as 155 Mb/s or higher.

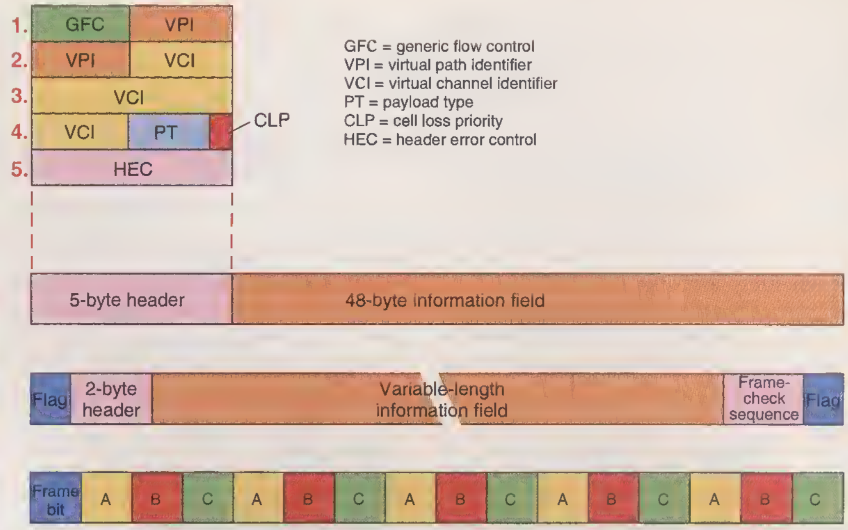
ATM is very flexible in the way it grants access to bandwidth. Its users are not obliged to buy wide-area bandwidth in network-sized increments (64 kb/s, 1.544 Mb/s, or 44.736 Mb/s) tied to the hierarchy of the digital telecommunications network. Instead ATM users send bursts of as many or as few cells as necessary to transfer their data; they also pay only for the cells they send, not for the speed of a dedicated facility they may use only part of the time.

THE ATM CELL. ATM is a connection-oriented technology—that is, every cell in an ATM transmission travels over the same route, which is specified either during call setup, in the case of switched service, or by provisioning, in the case of private line service. The header of an ATM cell [Fig. 1] contains all the information a network needs to relay the cell from one node to the next over the pre-established route. User data is contained in the remaining 48 bytes.

The header comprises several fields with the address contained in the three bytes labeled VPI and VCI. The first byte of the address contains the virtual path identifier (VPI) and the second two bytes make up the virtual channel identifier (VCI). This two-part addressing allows the network (or users) to use a short-hand notation for major trunks between locations while maintaining the identity of individual circuits within the trunk.

A virtual path may consist of several virtual channels. Hence, the VPI might represent a trunk between two cities and the VCIs might represent individual calls. Switching equipment along the way can route all the calls on the basis of just the first byte of the address (the VPI) without having to bother with the rest of the address until the trunk gets to the final location, where the traffic is distributed.

The remaining bits and bytes in the header maintain flow and ensure address integrity through the network.



[1] Packet-switching technologies like asynchronous transfer mode (ATM) and frame relay [top and middle] route traffic by means of addresses contained within the packets. In contrast, synchronous transfer mode (STM) technologies, like the very common T1 system, route data over dedicated physical paths that are established during call setup and remain fixed for the duration of a call [bottom]. Since STM data has no address, it is identified by its position (time slot) in a channel, which must not vary. Because frame relay is not based on fixed-length cells, it must use flags to denote the beginning and end of frames.

The degree to which the message is bound to the physical medium that carries it is another way in which networking is different for packet technologies like ATM as against STM services like voice. To repeat, STM services dedicate a physical path to a voice call for the duration of the call. For none of this time may any other call use any of these facilities. After the call is completed, everything is torn down and made available for use by the next call.

At the other extreme, so-called connectionless services have no path whatsoever associated with a communication. Each packet in a connectionless service may follow a different path from source to destination, depending upon which links are available at any given instant. This makes maximum use of network resources, but adds uncertainty to the time required for information to traverse the network. In fact, it is not unheard of for a packet to arrive at its destination before one that was transmitted earlier. While this presents no problem for digital data, which can be easily resequenced, it could wreak havoc with real-time services, like voice and video, which cannot afford the resequencing delay time.

VIRTUAL NETWORKING. ATM avoids either extreme. It uses the concept of virtual networking to pass traffic between two locations, establishing virtual connections between each pair of ATM switches needed to connect a source with a destination. These connections are termed "virtual" to distinguish them from the dedicated circuits of STM communications. Unlike the packets in a connectionless scheme, ATM packets always traverse the same path from source to destination; hence, ATM is a connection-oriented technology. But unlike STM technology, ATM does not reserve the path for one user exclusively. Any time a given user is not occupying a link, another user is free to use it.

ATM connections exist only as sets of routing tables held in each switch, based on the address contained in the cell header. Addresses in ATM are only of local significance, in that they matter only between two adjacent pieces of ATM equipment. When a virtual path is established, each switch is provided with a set of lookup tables that identify an incoming cell by header address, route it through the switch to the proper output port, and overwrite the incoming address with a new one that the next switch along the route will recognize as an entry in its routing table.

The message is thus passed from switch to switch over a prescribed route, but the route is "virtual" since the facility carrying the message is dedicated to it only while the cell traverses it. Two cells that are ultimately headed for different destinations may be carried, one after the other, over the same physical wire for the common portion of their journey.

It is the virtual nature of ATM services that will provide greater network efficiencies in the future. Today, most communications capacity is idle. A voice circuit is only 30–40 percent efficient; most of its time is spent listening. Data communications is apt to be equally inefficient. Transfer is often asymmetric, with large volumes of data flowing one way and only brief acknowledgments flowing the other way. LAN interconnections are even worse, with short, bursty transfers followed by silences.

By allowing several virtual connections to share the same physical facility, ATM can push efficiencies as high as the service provider dares push traffic statistics. In fact, one of the tariffing parameters of the future will be grade of service, based partly on

assurance of transport. Users may elect to pay lower rates for "best effort" service instead of guaranteed delivery for certain types of messages.

ATM LAN. Local-area networks are one of the most active application areas for ATM because the technology offers an entirely new approach to LAN architecture: centralized switching and control, rather than distributed access. Traditional LANs like Ethernet, Token Ring, and Fiber Distributed Data Interface (FDDI) depend on the sharing of a physical medium [Fig. 2, left]. Software at each station controls access to the physical bearer in accordance with rules established as part of the LAN standard. These rules arbitrate among users trying to use the shared medium at the same time.

The benefits of shared media are low media costs, simple physical wiring, and easy moves and changes. Media cost was an issue in the early days of Ethernet when large coaxial cable was used; it is still a concern with FDDI. Drawbacks of shared media include one-at-a-time access to the medium, the fact that all stations run at the same rate regardless of need, and loss of throughput during heavy use.

An ATM LAN replaces the shared medium with a centralized switch that has a dedicated connection for each user [Fig. 2, right]. Control of the network resides in the switch, which routes messages and controls access in the event of congestion. This topology is analogous to a private branch exchange (PBX) used for internal voice calls.

Each user in the ATM LAN has a line to a port on the switch that is shared with no one else. A user sends a message to the switch, which routes it to the destination indicated by the address in the header, just as a PBX routes a call to the extension number dialed. Because each port is dedicated to one user, the users do not have to contend for access as with conventional LANs. Throughout the call, the user has full access to the connection, regardless of the activity of other users with other such connections. If a 5-MB file is being transmitted, it moves in one continuous burst at the full channel rate instead of being segmented into shorter frames as with other LANs.

ATM also allows different users to communicate at different rates over different media. For example, engineers might use 155-Mb/s optical-fiber channels to the switch, while others might use lower-cost 1.544- or 51-Mb/s copper. This versatility makes it easier to tailor the network to specific needs without building in lots of excess capacity.

Finally, it is very easy to provide wide-area network (WAN) services to the LAN through another port on the LAN switch. Conventional LANs have no wide-area capabilities. They depend on a separate piece of equipment, either a bridge or a router, to convert the LAN rates and protocols into WAN-compatible formats. Using ATM, the LAN protocols and rates are already in WAN-compatible format; all that is required is another port on the LAN switch to connect to the WAN.

WAN APPLICATIONS. Early wide-area ATM services will probably be confined to private networking applications, with more generalized switched services emerging after 1995. In effect, corporations will be able to use ATM to tie scattered LANs together into a large corporate data network. However, they will not initially be able to connect up with the networks of others—to make "ATM phone calls."

Corporations today combine routers and dedicated leased lines into private data networks. The router connected to a LAN detects a message addressed to a station off the local network and directs it down the appropriate leased line to another router. The second router either drops the message onto its own local network or passes it to another router. The process is repeated until the message reaches the destination LAN [Fig. 3, top]. All this involves a lot of leased lines and, on a nationwide basis, can be quite expensive. As the figure makes evident, router networks tend to resemble meshes; that both reduces link congestion and provides backup in case of line failure.

As the number of users on LANs grows along with their need to communicate with users in other locations, the number of leased lines grows as does the necessary speed, rapidly driving expenses sky high. For example, a 1600-km 56-kb/s leased line costs about \$500 per month; a 1.544-Mb/s T1 line costs about \$6500, while a 45-Mb/s line (where and if available) costs about \$85 000 per month!

To top things off, these charges are independent of usage. Even if a line carries LAN traffic only 8 hours a day, 5 days a week, the user is charged for 24 hours a day, every day. Increasingly, companies need these high-speed connections to relieve congestion and increase throughput, but they need them only for a small part of the time. Until now, however, the network could sell data bandwidth only on a dedicated basis or by using unwieldy TDM switching technology.

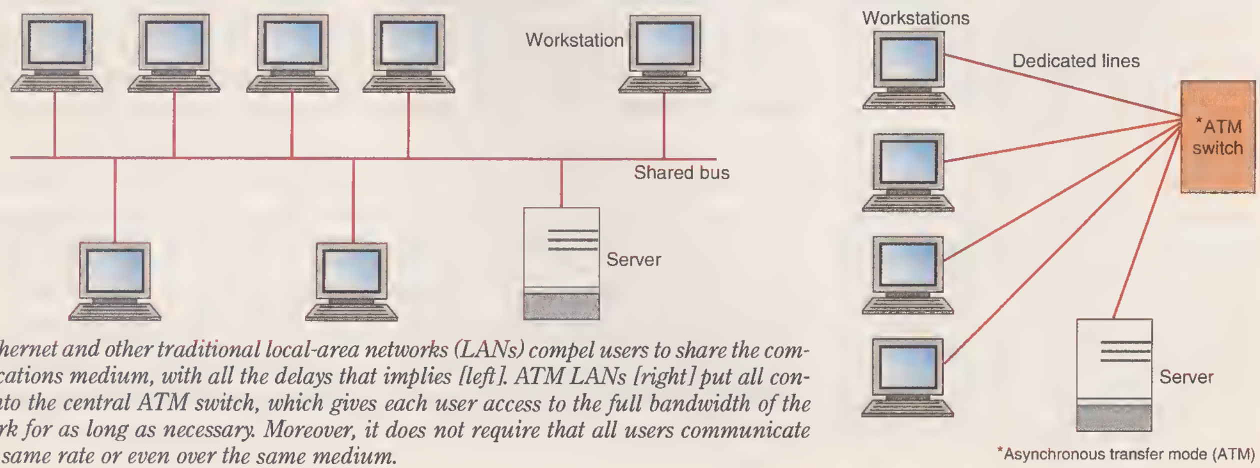
ATM can fix this problem. It can substitute a shared public facility for dedicated private facilities. Rather than a router at each location, requiring several dedicated lines, one connection would be provided from user premises to a public network ATM switch [Fig. 3, bottom]. Using a cell header address similar to that of the ATM LAN switch (it has four more bits), the network switch would route the data traffic from switch to switch, over shared wideband carrier facilities, until it was delivered to its destination.

Since the connection between user and network switch replaces several dedicated facilities used by bursty data traffic, its capacity can be less than the sum of the capacities of the lines it replaces. The public network gains similar efficiencies in its connections between switches. As a result, the costs of provisioning service are lower, which should result in lower costs to the user.

In fact, one of the capabilities ATM makes possible is billing on a per-cell basis (more probably on a gigacell basis, given the speed and transfer capabilities of ATM). Currently, service providers have no way of measuring actual information transfer or controlling usage on data communications circuits since LAN and router protocols are proprietary. The ATM cell provides a user format the carriers can recognize and count for usage-sensitive billing.

REALITY CHECK. ATM is clearly a sophisticated, well-conceived technology. But if it is to be successful, it has to fill a genuine need. Who needs it today, and what for?

ATM groupies reel off lists of exotic applications best served by ATM at every ATM conference. Multimedia, teleradiology, distance learning, desktop videoconferencing,



[2] Ethernet and other traditional local-area networks (LANs) compel users to share the communications medium, with all the delays that implies [left]. ATM LANs [right] put all control into the central ATM switch, which gives each user access to the full bandwidth of the network for as long as necessary. Moreover, it does not require that all users communicate at the same rate or even over the same medium.

image archiving, the paperless office, video electronic mail, global workgroup collaboration, and so on. The list is impressive, and all the cited applications need either the speed of ATM or its ability to handle mixtures of data and such timing-sensitive traffic as voice.

But videoconferencing has been just around the corner for 30 years, and most corporate decision makers have yet to perceive benefits from multimedia. The well-hyped applications of the future may need ATM to make them run, but do enough people need the applications to make ATM a success anytime soon?

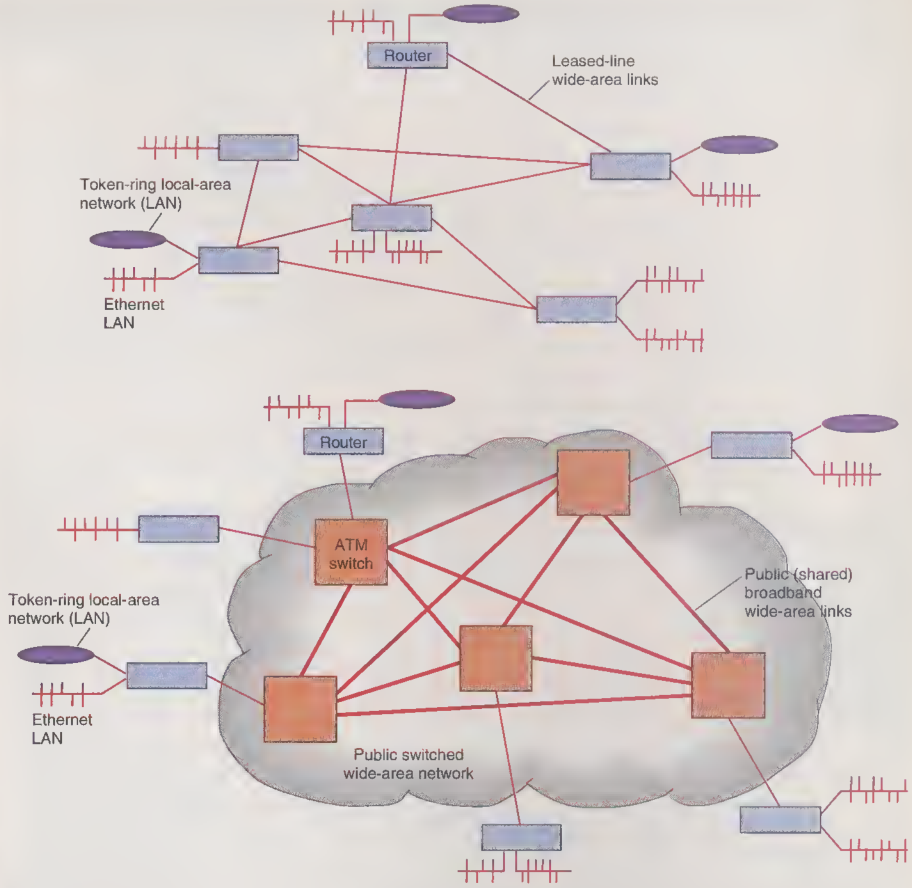
The answer is no, probably not. But have no fear. These glitzy applications are just sound-bite types of answers that mask a deeper, more complex problem that probably only ATM can solve. Both local- and wide-area networks are nearing the breaking point just carrying the loads generated by current applications. What may push the whole thing over the edge is not multimedia, but a steadily increasing amount of "ordinary" data traffic.

LAN administrators are already busily cutting up networks into smaller and smaller segments interconnected by local routers to keep workgroup throughput up. At the limit, the result of such surgery will be a dedicated LAN segment between each user and an Ethernet switch. This looks very much like an ATM LAN but without as much speed, without a high-speed channel to the local server, and without inherent compatibility with the wide-area network.

In the public network, about half of all traffic on corporate leased-line networks is data, and the amount is increasing at 10 times the rate of voice traffic. Already carriers are having trouble providing data services that match user needs (lots of bandwidth for a little time).

Now, mix in only one new capability—mobile computing in the form of third-generation descendants of Apple's Newton Message Pad, again running only conventional applications. This mobile application has the potential to explode as cellular phones did in the 1980s. Picture local wireless or infrared access from the device to the nearest LAN. Lots of people running around furiously scribbling notes, accessing text documents, graphics files, and spreadsheets (no need to invoke images, video, or voice), tapping into the LAN nearest them at any moment and being routed to their department LAN upstairs or across the country, and the result will be datacomm meltdown. Most people would surely find the ability to access a spreadsheet on their office PCs while sitting in a conference room on the other side of the building (or the other side of the country) more useful than video e-mail.

Not coincidentally, just as people are beginning to recognize these problems, along comes the solution in the form of ATM. It may be the only long-term solution to the problem facing the wide-area network—efficiently carrying voice or video services on the same network as data. And for LANs, it solves the speed-related problems created by the mounting volume of traffic generated by current applications. Moreover, unlike FDDI or other candidates, it provides two further benefits: it positions LANs for future multimedia applications if they appear, and it seamlessly integrates local traffic into the future wide-area ATM network.



[3] Wide-area data networks today are private affairs made from a combination of routers and leased lines [top]. As such, they tend to be expensive. The ATM solution [bottom] requires only one connection from a user's premises to a public network ATM switch. It employs a cell header address similar to that of an ATM LAN switch, but with four additional bits.

TO PROBE FURTHER. *Asynchronous Transfer Mode: Solution for Broadband ISDN*, 2nd ed., by Martin de Prycker (Ellis Norwood, London, 1993) provides an in-depth technical treatment of ATM. It is especially good on switching and congestion management. Another good book is *Asynchronous Transfer Mode Networks: Performance Issues* by Raif O. Onvural (Artech House, 1993).

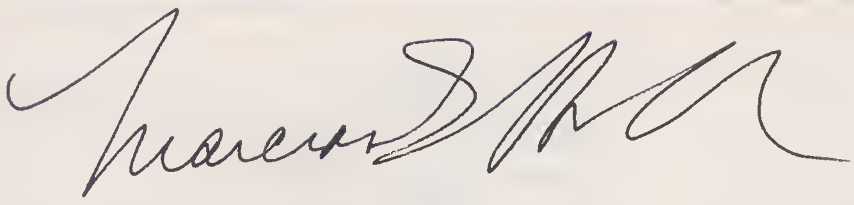
For those on a tight budget, *Asynchronous Transfer Mode: Bandwidth for the Future* by the present author, Jim Lane, Telco Systems, 1992, gives a high-level overview of ATM technology. The 64-page booklet is available from Advanstar Data (800-598-6008). Also by Jim Lane is the 44-page booklet *ATM over SONET: Seamless LAN/WAN Integration* (Integrated Telecom Technology, Gaithersburg, Md., 1993). The booklet emphasizes local-area network (LAN) applications of ATM and the Sonet physical layer.

An excellent source of technical information about various aspects of ATM is *IEEE Communications Magazine*, starting around September 1991. The articles are too numerous to cite separately.

Of course, the ultimate authorities on the subject are the standards documents from Bellcore. Among them are TA-NWT-1110: *BISDN Switching System Generic Requirements*; TA-NWT-1112: *BISDN UNI & NNI Physical Layer Generic Criteria*; TA-NWT-1113: *ATM & ATM Adaptation Layer Protocols Generic Requirements*; and TA-TSV-1408: *Generic Requirements for PVC Cell Relay Service*. These standards are available from Bellcore, 9 Corporate Place PYA-3A184, Piscataway, NJ 08854-4196; 800-521-2673.

Finally, for a description of the public and private ATM interfaces, including LAN interfaces not found in the Bellcore documents, see *ATM UNI Specification, Version 3.0* from the ATM Forum, c/o Interop Inc., 480 San Antonio Rd., Suite 100, Mountain View, CA 94040-1219; 415-962-2585. ◆

Jim Lane is president of TRAC Associates Inc., a telecommunications consulting firm in Sagamore, Mass. He has held engineering and marketing positions in the telecommunications and data communications fields for 25 years with firms such as Raytheon, Telco Systems, and TranSwitch.



The architect of the first microprocessor has turned detective, ferreting out the secrets of inventions hotly contested in patent court

The rays of the rising sun have barely reached the foothills of Silicon Valley, but Marcian E. (Ted) Hoff Jr. is already up to his elbows in electronic parts, digging through stacks of dusty circuit boards. This is the monthly flea market at Foothill College, and he rarely misses it.

Ted Hoff is part of electronics industry legend. While a research manager at Intel Corp., then based in Mountain View, he realized that silicon technology had advanced to the point that, with careful engineering, a complete central processor could fit on a chip. Teaming up with Stanley Mazor and Federico Faggin, he created the first commercial microprocessor, the Intel 4004.

But for Hoff, the microprocessor was merely one blip among many along the tracing of his long fascination with electronics. His passion for the field led him from New York City's used electronics stores to elite university laboratories, through the intense early years of the microprocessor revolution and the tumult of the video game industry, and ultimately to his job today: high-tech private eye.

KID POWER. Fairly early in his childhood Hoff figured out that the best way to feel less like a kid—and a little more powerful—was to understand how things work. He started his explorations with chemistry. By the age of 12 he had moved on to electronics, building things with parts ordered from an Allied Radio Catalog, a shortwave radio kit, and surplus relays and motors salvaged from the garbage at his father's employer, General Railway Signal Co., in Rochester, N.Y. Then in high school, working mostly with secondhand components, he built an oscilloscope, an achievement he parlayed into a technician's job at General Railway Signal.

Hoff returned to that job during breaks from his undergraduate studies at Rensselaer Polytechnic Institute, Troy, N.Y. Several summers began with Hoff entering the General Railway laboratory to find the researchers' two best oscilloscopes broken. He would repair the state-of-the-art Tektronix 545s, then move on to more interesting stuff, like inventing an audio frequency railroad-train tracking circuit and a lightning protection unit that gave him two patents before he was out of his teens.

The best thing about the job, Hoff recalled, was the access it gave him to components that were beyond the budgets of most engineering students in the 1950s—transistors, for instance, and even the just introduced power transistor. He did an undergraduate thesis on transistors used as switches, and the cash prize he won for it quickly went for a Heathkit scope of his own.

GO WEST. Hoff liked the engineering courses at Rensselaer, but not the narrow focus of the college itself. He wanted to broaden his perspective, both intellectually and geographically (he had never been more than a few miles west of Niagara Falls), so chose California's Stanford University for graduate school. While working toward his Ph.D. there, he did research in adaptive systems (which today are called neural networks) and, with his thesis advisor Bernard Widrow, racked up two more patents.

His Intel colleague Mazor, now training manager at Synopsys Inc., Mountain View, Calif., recalled meeting Hoff in his Stanford laboratory.

"He had a toy train moving back and forth under computer control, balancing a broomstick," Mazor said. "I saw him as a kooky inventor, a mad scientist."

After getting his degree, Hoff stayed at Stanford for six more years as a postdoctoral researcher, continuing the work on neural networks. At first, his group made the networks trainable by using a device whose resistance changed with the amount and direction of current applied. It consisted of a pencil lead and a piece of copper wire sitting in a copper sulfate and sulfuric acid solution, and they called it a memistor.

The group soon acquired an IBM 1620 computer, and Hoff had his first experience in programming—and in bucking the system. He had to deal with officials at the campus computer center who thought all computers should be in one place, run by specialists who handled the boxes of punched cards delivered by researchers. The idea that a researcher should program computer systems interactively was anathema to them.

"One result of all our work on microprocessors that has always pleased me," Hoff told *IEEE Spectrum*, "is that we got computers away from those people."

By 1968 student hostility to the government over the Vietnam War was growing and life for researchers on campus who, like Hoff, relied on government funding was looking as if it might get uncomfortable. Hoff had already been contemplating the possibilities of industrial jobs when he received a telephone call from Robert Noyce, who told him he was starting a new company, Intel Corp., and had heard Hoff might be interested in a job. He asked Hoff where the semiconductor integrated circuit business would find its next growth area. "Memories," Hoff replied.

That was the answer Noyce had in mind (Intel was launched as a memory manufacturer), and that year he hired Hoff as a member of the technical staff, Intel's 12th employee. Working on memory technology, Hoff soon received a patent for a cell for use in MOS random-access integrated circuit memory. Moving on to become manager of applications research, he had the first customer contact of his career.

"Engineering people tend to have a very haughty attitude toward marketing," Hoff said, "but I discovered you learn a tremendous amount if you keep your eyes and ears open in the field. Trying to understand what problems people are trying to solve is very helpful. People back in the lab who don't have that contact are working at a disadvantage."

ENTER MICROPROCESSOR. One group of customers with whom Hoff made contact were from Busicom Corp., Tokyo. Busicom had hired Intel to develop a set of custom chips for a low-cost calculator and had sent three engineers to Santa Clara to work on the chip designs. Hoff was assigned to look after them, getting them pencils and paper, showing them where the lunch room was—nothing technical.

But the technical part of Hoff's mind has no off-switch, and he quickly concluded that the engineers were going in the wrong direction. Twelve chips, each with more than 3000 transistors and 36 leads, were to handle different elements of the calculator logic and controls, and he surmised the packaging alone would cost more than the targeted retail price of the calculator. Hoff was struck by the complexity of this tiny calculator, compared with the simplicity of the PDP-8 minicomputer he was currently using in another project, and he concluded that a simple computer that could handle the functions of a calculator could be designed with about 1900 transistors. Given Intel's advanced MOS

Tekla S. Perry Senior Editor

Photos: Jon Brenneis

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VITAL STATISTICS

Name: Marcian E. (Ted) Hoff Jr.
Date of birth: Oct. 28, 1937
Place of birth: Rochester, N.Y.
Family: wife, Judy; three daughters, Carolyn, 30, Lisa, 26, and Jill, 24
Education: BS, 1958, Rensselaer Polytechnic Institute, Troy, N.Y.; MS, 1959, Ph.D., 1962, Stanford University, California, all in electrical engineering
First job: planting cabbages
First electronics job: technician, General Railway Signal Co., Rochester, N.Y.
Biggest surprise in career: media hysteria over the microprocessor
Patents: 17
Books recently read: *Introduction to Nuclear Reactor Theory* by John R. Lamarsh; *A Compiler Generator* by William M. McKeeman, James J. Horning, and David B. Wortman
People most respected: Intel Corp. founders Robert Noyce and Gordon Moore, Intel chief executive officer Andrew Grove
Favorite restaurants: Postrio and Bella Voce in San Francisco, Beausejour in Los Altos, Calif.
Favorite movies: *2001, Dr. Strangelove*
Motto: "If it works, it's aesthetic"
Leisure activities: playing with electronics; attending operas and concerts; going to the theater; bodysurfing in Hawaii; walking his Alaskan malamutes
Car: Porsche 944
Management creed: "The best motivation is self-motivation"
Organizational memberships: IEEE, Sigma Xi
Major awards: Stuart Ballantine Medal of the Franklin Institute, IEEE Cledo Brunetti Award, IEEE Centennial Medal, IEEE Fellow

process, all these, he felt, could fit on a single chip.

The Busicom engineers had no interest in dumping their design in favor of Hoff's unproved proposal. But Hoff, with Noyce's blessing, started working on the project. Soon Mazor, then a research engineer at Intel, joined him, and the two pursued Hoff's ideas, developing a simple instruction set that could be implemented with about 2000 transistors. They showed that the one set of instructions could handle decimal addition, scan a keyboard, maintain a display, and perform other functions that were allocated to separate chips in the Busicom design.

In October 1969, Hoff, Mazor, and the three Japanese engineers met with Busicom management, visiting from Japan, and described their divergent approaches. Busicom's managers chose Hoff's approach, partly, Hoff said, because they understood that the chip could have varied applications beyond that of a calculator. The project was given the internal moniker "4004."

Federico Faggin, now president and chief executive officer of Synaptics Inc., San Jose, Calif., was assigned to design the chip, and in nine months came up with working prototypes of a 4-bit, 2300-transistor "microprogrammable computer on a chip." Busicom received its first shipment of the devices in February 1971.

FRONT-RUNNER. Faggin recalled that when he began implementing the microprocessor, Hoff seemed to have lost interest in the project, and rarely interacted with him. Hoff was already working on his next project, the preliminary design of an 8-bit microprogrammable computer for Computer Terminals Corp., San Antonio, Texas, which, architected by Computer Terminals, was named the 8008. Hoff always "had to do very cutting-edge work," Faggin told *Spectrum*. "I could see a tension in him to always be at the forefront of what was happening."

In those early Intel days, Mazor recalled that Hoff had a number of ideas for projects, many of which, though not commercially successful, proved prescient: a RAM chip that would act like a digital camera and capture an image in memory, a video game with moving spaceships, a device for programming erasable programmable ROMs, and computer-aided design tools intended for logic simulation.

Meanwhile, the microprocessor revolution was gearing up, albeit slowly. Hoff joined Faggin as a microprocessor evangelist, trying to convince people that general-purpose one-chip computers made sense. Hoff said his toughest sell was to the Intel marketing department. "They were rather hostile to the idea," he recalled, for several reasons. First, they felt that all the chips Intel could make would go for several years to one company, so there was little point in marketing them to others. Second, they told Hoff, "We have diode salesman out there struggling like crazy to sell memories, and you want them to sell computers? You're crazy." And finally, they estimated that sales might total only 2000 chips a year.

But word went out. In May 1971 an article in *Datamation* magazine mentioned the product, and the following November Intel produced its first ad for the 4004 CPU and placed it in *Electronic News*. By 1972 stories about the miracle of what began being called the microprocessor started appearing regularly in the press, and Intel's competitors followed its lead by launching microprocessor products of their own.

One step Hoff did not take at that time was apply for a patent, even though he had already successfully patented several inventions. (Later, with Mazor and Faggin he filed for and was granted a patent for a "memory system for a multi-chip digital computer.") Looking back, Hoff recalled that he never even considered patenting the microprocessor in those days. To him the invention seemed to be obvious, and obviousness was considered grounds for rejecting a patent application (though, Hoff said bitterly, the patent office currently seems to ignore that rule). It was obvious to Hoff that if in one year a computer could be built with 1000 circuits on 100 chips, and if in the following year those 1000 circuits could be put onto 10 chips, eventually those 1000 circuits could be constructed on one chip.

Instead of patenting, Hoff in March 1970 published an article in the proceedings of the 1970 IEEE International Convention that stated: "An entirely new approach to design of very small computers is made possible by the vast circuit complexity possible with MOS technology. With from 1000 to 6000 MOS devices per chip, an entire central processor may be fabricated on a single chip."

But in December 1970, an independent inventor outside the cliquish semiconductor industry, Gilbert Hyatt, filed for a patent on a processor and mentioned that it was to be made on a single chip. In 1990, after numerous appeals and extensions, Hyatt was granted that patent and began collecting royalties from many microprocessor manufacturers. Currently, though history traces today's microprocessor back to Hoff, Mazor, and Faggin, the legal rights to the invention belong to Hyatt.

CODEC CHALLENGE. While the microprocessor has proved to be his most celebrated achievement, Hoff does not view it as his biggest technical breakthrough. That designation he reserves for the single-chip analog-to-digital/digital-to-analog coder/decoder (codec).

"Now *that* work was an exciting technical challenge," Hoff recollected with some glee, "because there were so many who said it couldn't be done."

The project was kicked off by Noyce, who spotted the telephone industry as ripe for new technology, and urged Hoff to find an important product for that market. Studying telephone communications, Hoff and several other researchers saw that digitized voice transmission, then being used between central offices, depended on the use of complex expensive codecs that tied into electromechanical switches.

"We thought," Hoff told *Spectrum*, "we could integrate this, the analog-to-digital conversion, on a chip, and then use these circuits as the basis for switching." Besides reducing the cost of the systems to the telephone company, such chips would enable companies to build small branch exchanges that handled switching electronically.

Hoff and his group developed a multiplexed approach to conversion in which a single converter is shared by the transmit and receive channels. They also established a number of other techniques for conversion and decoding that Hoff saw as not being obvious and for which he received patents.

With that project's completion in 1980, after six years of effort, and its transfer to Intel's manufacturing facility in Chandler, Ariz., Hoff became an Intel Fellow, free to pursue whatever technology interested him. What interested him was returning to his work on adaptive structures, combining the concepts he had wrestled with at Stanford with the power of the microprocessor in the service of speech recognition. After a year he built a recognition system that Intel marketed for several years.

A prime customer for the system was the automotive industry. Its inspectors used the systems to help them check out a car as it finally left the assembly line. When an inspector noted out loud various problems that needed fixing, the system would prompt him for further information, and log his responses in a computer.

NEW GAME. Though his position as an Intel Fellow gave Hoff a fair amount of freedom, he found himself getting bored. Intel's success in microprocessors by 1983 had turned it into a chip supplier, and other companies were designing the chips into systems. "I had always been more interested in systems than in chips," Hoff said, "and I had been at Intel for 14 years, at a time when the average stay at a company in Silicon Valley was three years. I was overdue for a move."

Again, Hoff had not gone beyond thinking about leaving Intel when a new job came to him. Atari Inc., Sunnyvale, Calif., then a booming video game company owned by Warner Communications Inc. and a major user of microprocessors, was looking for a vice president of corporate technology. In February 1983, after discussing the scope of the ideas that Atari researchers were pursuing, Hoff latched onto the opportunity.

Intel from the start had a structured, highly controlled culture. At Atari, chaos reigned. Under Hoff were research laboratories in Sunnyvale, Los Angeles, and Grass Valley, Calif.; Cambridge, Mass.; and New York City. Researchers were working on picture telephones, electronic aids for joggers, computer controls that gave tactile feedback, graphical environments akin to today's virtual reality, digital sound synthesis, advanced personal computers, and software distribution via FM sidebands.

'People who don't question the assumptions made going into a problem often end up solving the wrong problem'—Ted Hoff

But Hoff had barely had time to learn about all the research projects under way before the video game business took a well-publicized plunge. Without solid internal controls, Atari was unable to determine how well its games were selling at the retail point, and distributors were returning hundreds of thousands of cartridges and game machines. Hoff began receiving orders for staff cuts monthly.

"It would have been one thing if I had known I had to cut back to, say, one-quarter the size of my group," he told *Spectrum*. "But when every month you find you have to cut another chunk, morale really drops."

In July 1984, while Hoff was at his 30th high school reunion, Warner sold Atari to Jack Tramiel. Hoff then had to choose between convincing Tramiel that he could play a role in a narrowly focused company uninterested in funding futuristic research, and allowing Warner to buy out his contract. He chose the latter.

Looking back, most of the people who were at Atari in those days now view them darkly. But Hoff recalls his year there as an enjoyable and ultimately useful experience. "Maybe I look at it more positively than I should," he said, "but it turned out to be a good transition for me, and the life I have now is a very nice one."

TINKERER FOR HIRE. He now spends half his time as a consultant and half pursuing technical projects of his own devising—a readout device for machine tools, various types of frame grabbers, pattern recognition, and techniques for analog-to-digital conversion. This variegated schedule is perfect for him. He has always felt himself to be a generalist, and has had trouble focusing on just one technology.

"It's easy for me to get distracted," he said. "Whenever you are working on one problem, there is always another problem over here that seems more interesting. But now it is more likely that my own projects get delayed, rather than things critical to other people and their employment."

Faggin for one is not surprised that such independent work appeals to Hoff. "He never was the gregarious type," Faggin said. "He liked introverted work, the thinking, the figuring out of new things. That is what he is good at. I always was impressed how he was able to visualize an architecture for a new IC, practically on the spot."

Said Gary Summers, president and chief executive officer of Teklicon Inc., Mountain View, the consulting firm that employs Hoff today: "He comes up with idea after idea, situation after situation. I think if he wanted to, Ted could sit down and crank out a patent a month."

"There is no doubt in my mind that he is a genius," Mazor stated. Summers readily concurred.

Hoff's first project after Atari was a voice-controlled music synthesizer, which gave off the sound of a selected instrument when someone sang into it. Hoff's biggest contribution to the project was a system that ensured that the emerging notes would be in tune, or at least harmonically complement the tune, even when the singer strayed off key. He scored another patent for this system, and the gadget was sold briefly through the *Sharper Image* catalog, but never became a big success.

Hoff still contributes occasionally to product designs. At Teklicon, however, where he is vice president and chief technical officer, most of his consulting is done for lawyers. Hoff has a unique combination of long experience with electronic design and long-standing pack-rat habits. His home workshop contains about eight personal computers of different makes and vintages, five oscilloscopes, including a vintage Tektronix 545 scope, 15 000 ICs inventoried and filed, and shelves loaded with IC data books dating right back to the 1960s.

When a lawyer shows him a patent disclosure, even one decades old, he can determine whether or not it could then have been "reduced to practice" and whether it provided sufficient information to allow "one of ordinary skill in the art" to practice the invention. Then he can build a model proving his conclusion, using vintage components from his collection, and demonstrate the model in court as an expert witness. This model-building can get very basic. On *Spectrum's* visit, Rochelle salt crystals that Hoff attempted to grow for a recent court demonstration littered his workshop floor, next to metal-working equipment that he uses to build cases for his models.

Hoff sees this ability to get down to basics as one of his strengths. "I relate things to fundamental principles," he said. "People who don't question the assumptions made going into a problem often end up solving the wrong problem."

Mazor said, "If my washing machine breaks down, I call the repairman. Most clever engineers would buy the replacement gear and install it. Ted is capable of analyzing the reason the gear failed in the first place, redesigning a better gear from basic principles, carving it out of wood, casting it at his home, and dynamically balancing it on his lathe before installing it."

Doing legal detective work appeals to Hoff for another reason: it gives him an excuse to hunt for interesting "antique" components at flea markets and electronics stores.

WHERE CREDIT IS DUE. Hoff cannot discuss the specifics of patent cases he has been involved with. Several recently were in the video game area; others have involved various IC companies. In a number of cases, Hoff was confident that his side was right, and his side still lost, so he felt little surprise when the microprocessor patent was granted to Hyatt. (After the award was made, though, he did sit down with Hyatt's patent application and attempted to design a working microprocessor based on Hyatt's disclosures. He found several incongruities—like a clock rate only suited to bipolar technology with logic that could only be rendered in MOS technology, and logic that required far too many transistors to put on a chip, proving in his mind that the award was incorrect.)

Seeing someone else get credit for the microprocessor, particularly in recent media reports, "is irritating," Hoff told *Spectrum*, "but I'm not going to let it bother me, because I know what I did, I know what all the other people on our project did, and I know what kind of company Intel is. And I know that I was where the action was." ◆

Calendar

(Continued from p. 11)
David M. Hanttula, 26787 Robleda Court, Los Altos Hills, CA 94022; 415-656-1661.

Sixth International Conference on Indium Phosphide and Related Materials—IPRM (ED, LEO); March 28–31; Red Lion Resort, Santa Barbara, Calif.; Susan Evans, IEEE/LEOS, 445 Hoes Lane, Box 1331, Piscataway, NJ 08855-1331; 908-562-3896; fax, 908-562-1571.

National Radar Conference (AES, Atlanta Section); March 29–31; Holiday Inn Crowne Plaza Ravinia, Atlanta, Ga.; Robert N. Trebits, Georgia Tech Research Institute, 7220 Richardson Rd., Smyrna, GA 30080; 404-528-7769; fax, 404-528-7883.

Southcon '94 (Region 3, Florida Council); March 29–31; Orange County Convention/Civic Center, Orlando, Fla.; JoAnn Lindberg, ECM, 8110 Airport Blvd., Los Angeles, CA 90045; 800-877-2668; fax, 310-641-5117.

APRIL

Second International Conference on Ultra-Wideband, Short-Pulse Electromagnetics (MTT); April 5–7; Weber Research Institute, Polytechnic University, Brooklyn, N.Y.; Lawrence Carin, Polytechnic University, 333 Jay St., Brooklyn, NY; 718-260-3600; fax, 718-260-3136.

Southeastcon '94 (Region 3, et al.); April 10–13; Hyatt Regency Hotel, Miami, Fla.; Osama A. Mohammed, Department of Electrical Engineering, Florida International University, University Park Campus, Miami, FL 33199; 305-348-3040; fax, 305-348-3707.

Transmission and Distributed Conference and Exhibition (PE, Chicago Section); April 10–15; McCormick Place, Chicago; John J. Viera, Commonwealth Edison, Box 767, Chicago, IL 60690; 312-294-3333.

International Reliability Physics Symposium (ED, R); April 11–14; Fairmont Hotel, San Jose, Calif.; Richard Blish, Intel Corp., 5000 W. Chandler Blvd., Chandler, AZ 85226; 602-554-4127; fax, 602-554-6098.

Third Maghrebian Conference on Software Engineering and Artificial Intelligence (C); April 11–14; Hyatt Regency Hotel, Rabat-Agdal, Morocco; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1992; 202-371-1013; fax, 202-728-0884.

Position, Location and Navigation Symposium—Plans '94 (AES); April 11–15; Bally's Hotel, Las Vegas, Nev.; Michael Hadfield, 12449 84th Way N., Largo, FL 34643; 813-531-5715.

International Symposium on Speech, Image Processing and Neural Networks (SP, Hong Kong Section); April 14–16; Hong Kong Convention and Exhibition Centre; Chorkin Chan, Department of CS, University of Hong Kong, Hong Kong; (8+52) 859 7075; fax, (8+52) 559 8447; e-mail, cchan@csd.hku.hk.

International Conference on Requirements Engineering (C); April 18–22; Broadmoor Hotel, Colorado Springs, Colo.; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1992; 202-371-1013.

International Conference on Acoustics, Speech and Signal Processing (SP); April 19–22; Adelaide Convention Center, South Australia; Phil Plevin, Plevin & Associates Pty., Box 54, Burnside 5066, South Australia; (61+8) 379 8222; fax, (61+8) 379 8177.

Southwest Symposium on Image Analysis and Interpretation (SP, Dallas Section); April 21–22; Grand Kempinski Hotel, Dallas; Alireza Khotanzad, Southern Methodist University; 214-768-3101; fax, 214-768-3883; e-mail, kha@seas,smu.edu; or Nasser Kehtarnavaz, Texas A&M University; 409-845-8371; fax, 409-845-6259; e-mail, kehtar@ee.tamu.edu.

Rural Electric Power Conference (IA); April 24–26; Sheraton Colorado Springs Hotel, Colorado; Donald E. Werner, Omaha Public Power District, 444 South 16th St., Mall, Omaha, NE 68102-2247; 402-636-2585.

International Workshop on Computer-Aided Modeling, Analysis, and Design of Communication Links and Networks—Camad '94 (COM); April 24–27; Princeton Marriott Hotel, New Jersey; Benjamin Melamed, NEC USA Inc., 4 Independence Way, Princeton, NJ 08540; 609-951-2450.

ACM Conference on Human Factors in Computer Systems (C); April 24–28; Hynes Convention Center, Boston; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1992; 202-371-1013; fax, 202-728-0884.

VLSI Test Symposium (C, Philadelphia Section); April 25–28; Cherry Hill Hyatt Hotel, New Jersey; Prab Varma, CrossCheck Technology, 2833 Junction Ave., San Jose, CA 95134; 408-432-9200; fax, 408-432-0907; e-mail, prab@crosscheck.com.

44th Electronic Components and Technology Conference—ECTC '94 (CHMT); April 30–May 5; Washington Hilton Hotel, D.C.; James Bruorton, Kernet Electronics, Box 5928, Greenville, SC 29606; 803-963-6621; fax, 803-963-6521.

MAY

Custom Integrated Circuits Conference—CICC '94 (ED, SSC); May 1–4; Town & Country Hotel, San Diego, Calif.; Melissa Widerkehr, Widerkehr and Associates, Suite 610, 1545 18th St., N.W., Washington, DC 20036; 202-986-2166; fax, 202-986-1139.

Industrial & Commercial Power Systems Technical Conference—I&CPS (IA, Orange City); May 1–5; Radisson Plaza Hotel, Irvine, Calif.; Farrokh Shokooh, Electrical Engineering Operation Tech. Inc., C.O.A., 17870 Skypark Circle, Suite #102, Irvine, CA 92714; 714-476-8117.

International Conference on Communications—ICC Supercomm '94 (COM); May 1–5; Ernest N. Morial Convention Center, New Orleans, La.; Eddie Sawaya, South Central Bell Telephone Co., 365 Canal St., Room 710, New Orleans, LA 70140; 504-528-2673; fax, 504-528-7170.

International Symposium on Electronics and the Environment (TAB); May 2–4; San Francisco Airport Marriott, California; Conference Registrar, IEEE Technical Activities, 445 Hoes Lane, Box 1331, Piscataway, NJ 08855-1331; 908-562-3878.

Offshore Technology Conference—OTC '94 (OE); May 2–5; Astrodomain Complex, Houston, Texas; Deborah Wheeler, Box 833868, Richardson, TX 75083-3868; 214-952-9494; fax, 214-952-9435.

Conference on Lasers & Electro-Optics and the International Electronics Conference—CLEO/IQEC (LEO); May 8–13; Anaheim Convention Center, California; IEEE/LEOS, 445 Hoes Lane, Box 1331, Piscataway, NJ 08855-1331; 908-562-3893.

International Conference on Robotics and Automation (RA); May 8–13; San Diego Princess Resort, California; Harry Hayman, Box 3216, Silver Spring, MD 20918; 301-236-5621; fax, 301-236-5621.

Electro '94 (Region 1, et al.); May 10–12; Hynes Convention Center, Boston; Sharon Schifano, Miller Freeman Inc., 13760 Noel Rd., Suite 500, Dallas, TX 75240; 800-527-0207; fax, 214-419-7915.

Instrumentation & Measurement Technology Conference—IMTC '94 (IM); May 10–12; Grand Hotel Hamamatsu, Japan; Robert Myers, Myers/Smith Inc., 3685 Motor Ave., Suite 240, Los Angeles, CA 90034–5750; 310-287-1463; fax, 310-287-1851.

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Semiconductor Device Modeling with SPICE, 2nd edition. *Massobrio, Giuseppe*, and *Antognetti, Paolo*, McGraw-Hill, New York, 1993, 479 pp., $55.

Semiconductor Physical Electronics. *Li, Sheng S.*, Plenum Publishing, New York, 1993, 507 pp., $65.

JPEG: Still Image Data Compression. *Pennebaker, William B.*, and *Mitchell, Joan L.*, Van Nostrand Reinhold, New York, 1993, 656 pp., $59.95.

Networks of Power: Electrification in Western Society, 1880–1930. *Hughes, Thomas P.*, Johns Hopkins University Press, Baltimore, Md., 1993, 474 pp. $34.95.

Working with Word 5.1, 3rd edition. *Kinata, Chris,* and *McComb, Gordon,* Microsoft Press, Redmond, Wash., 1993, 816 pp., $29.95.

Real-Time and Systems Programming for PCs: Using the iRMX for Windows Operating System. *Vickery, Christopher*, McGraw-Hill, New York, 1993, 604 pp., $29.95.

The Science and Practice of Welding: Vol. 2: The Practice of Welding. *Davies, A.C.*, Cambridge University Press, New York, 1993, 521 pp., $79.95 (hardcover), $29.95 (paperback).

VMS for Alpha Platforms Internals and Data Structures, preliminary edition, Vol. 3. *Goldenberg, Ruth E.*, and *Saravanan, Saro*, Digital Press, Maynard, Mass., 1993, 300 pp., $30.

How to Build and Manage a Winning Project Team. *Lewis, James P.*, Amacom, New York, 1993, 224 pp., $26.95.

MS-DOS 6 Companion. *Woodcock, JoAnne*, Microsoft Press, Redmond, Wash., 1993, 720 pp., $27.95.

MS-DOS to the Max: Tools and Techniques That Will Make Your Hard Disk Scream. *Gookin, Dan,* Microsoft Press, Redmond, Wash., 1993, 336 pp., $ 29.95.

VAXcluster Principles. *Davis, Roy G.*, Digital Press, Maynard, Mass., 1993, 600 pp., $49.95.

dBASE IV 1.5 HOTLINE Q&A. *Biegel, Richard*, and *Pendharkar, Sumant*, Van Nostrand Reinhold, New York, 1993, 380 pp., $35.95.

McGraw-Hill Encyclopedia of Engineering, 2nd edition. *Parker, Sybil P.*, McGraw-Hill, New York, 1992, 1414 pp., $95.90.

NAS Architecture Reference Manual. *Laverdure, Leo, et al.*, Digital Press, Maynard, Mass., 1993, 525 pp., $34.95.

Revitalizing U.S. Electronics: Lessons from Japan. *Sprague, John*, Butterworth-Heinemann, Stoneham, Mass., 1993, 262 pp., $34.95.

CICS Essentials: For Application Developers and Programmers. *Le Bert, Joseph J.*, McGraw-Hill, New York, 1993, 440 pp., $45.

Understanding Microwaves. *Scott, Allan W.*, John Wiley & Sons, New York, 1993, 545 pp., $54.95.

Software Engineering and CASE: Bridging the Culture Gap. *Flecher, Tom*, and *Hunt, Jim*, McGraw-Hill, New York, 1993, 277 pp., $40.

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The Advanced Technology Center for Photonics and Optoelectronic Materials (ATC/POEM) seeks application for the position of Associate Director for Technical Liaison. The ATC/POEM, established in 1989 by the State of New Jersey, is an interdisciplinary research and educational activity centered in the School of Engineering and Applied Science (SEAS) at Princeton University. The Center is primarily concerned with advanced research, engineering and transfer of photonic materials, device and systems technology to the industrial sector.

The Associate Director will be responsible for coordinating technology transfer programs, establishing contacts between companies and POEM faculty, working with the Princeton University Office of Research and Projects Administration in implementing sponsored research and intellectual property agreements, acting as a general technical liaison between POEM and the New Jersey photonics industry, and serving as executive assistant to the POEM Director. Also, coordinating joint activities between POEM, SEAS, and the Princeton Materials Institute fall within the scope of activities of the Associate Director.

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The Token-Ring Management Guide. *Nemzow, Martin A.W.*, McGraw-Hill, New York, 1993, 491 pp., $48.

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Placement and Routing of Electronic Modules. Ed. *Pecht, Michael*, Marcel Dekker, New York, 1993, 352 pp., $125.

Measurements for Competitiveness in Electronics, 1st edition. *NIST*, National Institute of Standards and Technology, Gaithersburg, Md., 1993, 448 pp., $52 (print), $19.50 (microfiche).

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Writing Solid Code: Microsoft's Techniques for Developing Bug-Free Programs. *Maguire, Steve*, Microsoft Press, Redmond, Wash., 1993, 288 pp., $24.95.

Design's Impact on Logistics. *AT&T Co.*, McGraw-Hill, New York, 1993, 228 pp., $42.

Code Complete: A Practical Handbook of Software Construction. *McConnell, Steve*, Microsoft Press, Redmond, Wash., 1993, 880 pp., $35.

Element of Risk: The Politics of Radon. *Cole, Leonard A.*, AAAS Press, New York, 1993, 246 pp., $29.95.

Testing to Verify Design and Manufacturing Readiness. *AT&T Co.*, McGraw-Hill, New York, 1993, 239 pp., $40.

The Electrical Engineering Handbook. Ed. *Dorf, Richard C.*, CRC Press, Boca Raton, Fla., 1993, 2700 pp., $89.95.

Mind Over Media: Creative Thinking Skills for Electronic Media. *Von Wodtke, Mark*, McGraw-Hill, New York, 1993, 343 pp., $32.95.

The Emergence of Artificial Cognition: An Introduction to Collective Learning. *Bock, Peter*, World Scientific Publishing, River Edge, N.J., 1993, 323 pp., $32.

Chemical Searching on an Array Processor. *Wilson, Terence*, John Wiley & Sons, New York, 1993, 197 pp., $115.

Incompressible Computational Fluid Dynamics: Trends and Advances. *Gunzburger, Max D.*, and *Nicolaides, Roy A.*, Cambridge University Press, New York, 1993, 481 pp., $59.95.

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UNIX Internetworking. *Pabrai, Uday O.*, Artech House, Norwood, Mass., 1993, 197 pp., $65.

Engineering Economic Analysis: An Introduction. *Lindeburg, Michael R.*, Professional Publications, Belmont, Calif., 1993, 231 pp., $15.95.

Expert Systems in Business and Finance: Issues and Applications. *Watkins, Paul R.*, and *Eliot, Lance B.*, John Wiley & Sons, New York, 1993, 367 pp., $49.95.

Untangling Organizational Gridlock: Strategies for Building a Customer Focus. *Bechtell, Michelle L.*, Amacom, New York, 1993, 347 pp., $27.95.

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Cooper Union. Tenure track assistant professor. Electrical Engineering. Duties include teaching undergraduate electronics, directing undergraduate electronics, projects, and supervising master's theses candidates. Research is encouraged through the Cooper Union Research Foundation. Only candidates with a strong interest in laboratory development should apply. Ph.D. required. Please contact Dr. Melvin Sandler, The Cooper Union, 51 Astor Place, N.Y., N.Y. 10003. Cooper Union is an equal opportunity affirmative action employer.

Department of Electrical Engineering at Royal Melbourne Institute of Technology (RMIT) Melboume, Australia offers 2 postdoctoral fellowships in micro mechatronics and micro machine technology. The research is partially supported by the Japanese Micro Machine Centre, under a research program sponsored by NEDO, an agency of the Japanese Ministry of International Trade and Industry (MITI). The positions are available until April 1995 with the possibility of renewal until April 1996. Applicants should have a Ph.D. (or near completion) in the fields of Physics, Engineering, Materials Science or Chemistry. Experience in micro mechanics and micro machines preferred. Qualified applicants should send their curriculum vitae, qualifications, and the names, addresses and fax numbers of 2 referees, by 28 Feb 1994. Applications should be addressed to the Appointments Officer, Human Resources Management Group, G.P.O. Box 2476V, Melbourne, Victoria, 3001 Australia. Salary in the range of A$36,285 - A$38,950. Further information and a position description contact Dr. Ronald B. Zmood, ph 61 3 660 2100 or fax 61 3 660 2007 or email: rzmood@rmit.edu.au. Equal opportunity is university policy.

Microfabrication Engineer/Scientist. The Physics and Astronomy Department at Michigan State University is seeking a person to operate and maintain a microfabrication facility with electron-beam and optical lithographies and with electron imaging and analysis. Instrumentation includes JEOL 840A and ISI SX40 SEM's equipped for electron-beam writing under computer control, and a VG 501 FESTEM. Responsibilities include: operation and maintenance of electron beam and optical lithography devices and FESTEM facility; TEM sample preparation; training of students in lithography and microscopy; development of electron-beam lithography techniques; and participation in research programs with faculty and students. Requires a high school education plus two or three years of college, technical or vocational school in digital/analog electronics and instrumentation; five years of related and progressively more responsible or expansive work experience in the operation, maintenance, and use of electron-beam lithography and electron microscope facilities including basic lab techniques, lab safety techniques, overseeing lab operations and use of specialized equipment. Additional experience in condensed matter physics (x-ray, electronics, spectroscopy) will be viewed favorably. Call 517-336-1662 for an application. Refer to position #P30104. MSU is an Affirmative Action/Equal Opportunity Institution. Qualified minorities and women are encouraged to apply for this position.

Electrical Engineer. The Department of Applied Sciences of the College of Staten Island of the City University of New York is seeking to fill a tenure-track position in Electrical Engineering Science as of September 1, 1994. The position is open to qualified applicants at the assistant or associate professor level, with salaries ranging from $30,000 to $60,000 per academic year according to qualifications. A PhD in Electrical Engineering is required. Post doctoral experience is highly desirable. Candidates with specialization in the areas of signal processing or electro-optics are preferred. This position requires teaching in an ABET accredited Engineering Science program. A successful candidate is also expected to develop a vigorous, nationally recognized research program. Evaluation of candidates will commence on March 1, 1994 and continue until the position is filled. Send curriculum vitae; a statement of research plans; names, addresses, and telephone numbers of three references to: Professor P. Razelos, The College of Staten Island of the City University of New York, 2800 Victory Blvd., room 1N-228, Staten Island, N.Y. 10314. Equal Opportunity/Affirmative Action Employer.

The Department of Electrical and Computer Engineering at Kansas State University invites applications for a tenure track position at the rank of assistant or associate professor. Applications of highly qualified candidates with an earned doctorate in electrical power systems, or related areas, will be considered. Good written and verbal communication skills are essential. Candidates should expect to teach undergraduate and graduate electrical engineering courses, advise M.S. and Ph.D. students, contribute to the Master's program with power systems emphasis via television for the Kansas City Educational Network, and conduct research and attract funding in their field of specialization. A record of publications or demonstrated potential for independent research is necessary. The position is available for Fall 1994. Letters of application, resumes and a list of three professional references should be directed to David L. Soldan, Head, Department of Electrical and Computer Engineering, 261 Durland Hall, Kansas State University, Manhattan, KS 66506-5105. Applications will be reviewed starting February 15, 1994. The last date for receipt of applications is April 2, 1994. KSU is an equal opportunity/affirmative action employer. Women and minorities are encouraged to apply.

Computer Engineering or Computer Science: Tenure-track position in Computer Engineering or Science Fall 1994. Our department, an exciting mix of 23 engineers, computer scientists and physicists, offers opportunities for research, innovative teaching and diverse consulting in an exceptionally collegial atmosphere. Submit a vita, a letter describing teaching experience and research, and three letters of reference to be sent by Mar. 1, 1994 to Randall Caton, CNU, Newport News VA 23606. (email:rcaton@pcs.cnu.edu). An AA/EO Employer. Women and minorities are strongly urged to apply.

Dartmouth College, Thayer School of Engineering. Faculty Positions in Computer Engineering. Dartmouth College invites applications for computer engineering faculty positions at all levels, especially junior. Requirements include an earned doctorate in computer engineering, computer science, electrical engineering or related field. In addition, applicants should present evidence of excellence, or potential for excellence, in teaching and research. All areas of computer engineering will be considered, but specialization in high performance computer systems, scientific computing, computer communications or graphics/visualization technology will be given preference. Responsibilities include teaching at the undergraduate and graduate levels, conducting funded research and advising graduate student in the engineering and computer science Ph.D. programs. Dartmouth College is a small, highly selective university with graduate programs in the sciences, engineering, business administration and medicine. Dartmouth faculty currently have research interests that include visualization for scientific and medical computing, signal image processing, performance analysis, scientific computing, rapid prototyping, multimedia systems, and parallel systems and algorithms. The campus is located in a small New England town with airline service to Boston and New York, interstate highway access (two hours by car from Boston, three hours from Montreal) and Amtrak rail service to New York and Montreal. The area is known for its excellent outdoor and cultural activities. Applications with current resumes and the names of at least four references should be sent to: Professor George Cybenko, Computer Engineering Search Chair, Thayer School of Engineering, Dartmouth College, Hanover, NH 03755-8000, USA. Review of applications will begin February 1, 1994. Dartmouth College is an Equal Opportunity/Affirmative Action employer and encourages applications from women and members of minority groups.

Assistant Professor of Electrical Engineering. Applications are being accepted for a tenure-track position in the Department of EECS at the University of Wisconsin-Milwaukee (UWM). Departmental primary needs are in the areas of applied electromagnetics, including remote sensing, communications and opto-electronics, although outstanding candidates in other EE areas may be considered. Applicants must have a Ph.D. in electrical engineering or a closely related field. In addition to a strong commitment to teaching, the candidate for this position is also expected to build a strong research program, which can be integrated into the existing programs of the department. Submit curriculum vitae, bibliography and a list of (3) references to: Dr. David Yu, Co-Chair for Electrical Engineering, Department of EECS, UWM, P.O. Box 784, Milwaukee, WI 53201. The deadline for application is March 31, 1994. The University is an Affirmative Action/Equal Opportunity Employer, women and minorities are strongly encouraged to apply. The names of those applicants who have not requested that their identities be withheld and the names of all finalists will be released on request.

The Johns Hopkins University, Department of Computer Science, Center for Speech Processing. The Johns Hopkins University invites applications for a new faculty position in the Department of Computer Science in conjunction with the Center for Speech Processing of the G.W.C. Whiting School of Engineering. Appointments at all ranks will be considered. We are particularly - but not exclusively - seeking candidates with research/teaching interests in the area of spoken language systems, especially language modeling, acoustic signal processing, automatic learning of grammars and semantics from text corpora, machine language translation, and construction of dialogue systems. An interest in utilizing statistical methods of parameter estimation for self-organization is also preferred. Finally, a willingness to participate in collaborative projects involving systems building and software implementation is essential. This will be a tenure-track position in the Department of Computer Science with primary research involvement associated with the Center for Speech Processing. All applicants are expected to have an outstanding research record, commitment to quality teaching, and the ability and willingness to develop a research program of the highest quality. Applicants should send a comprehensive vita and names of at least three references to: CS-CSP Faculty Search Committee, Department of Computer Science, Room 224, New Engineering Building, Johns Hopkins University, Baltimore, Maryland 21218-2694. Fax: (410) 516-6134. email: cs_csp_position@cs.jhu.edu The Johns Hopkins University is an equal opportunity/affirmative action employer. Minorities and women are strongly encouraged to apply.

Carnegie Mellon University. The department of Electrical and Computer Engineering at Carnegie Mellon University invites applications for a tenure track position at the Assistant Professor level. We are seeking highly qualified candidates who are committed to a career in research and teaching. We are especially interested in a candidate with a strong theoretical and experimental background in control theory and its applications in one or more areas including, but not limited to: intelligent sensors and actuators, intelligent structures, micromechanisms, fault tolerant control systems, human interfaces for real-time control, manufacturing, and robotics. The successful candidate will have the opportunity to form collaborations with one or more active research groups both within and outside the department. The department has active research programs in magnetic recording, optical computing, CAD, real-time systems, signal processing and telecommunications, robotics and controls, MEMS, and solid state devices. Besides, Carnegie Mellon has several research centers that offer the opportunity for collaboration. These include Engineering Design Research Center (a NSF-ERC), Data Storage Systems Center (a NSF-ERC), The Robotics Institute, SRC-CAD Center, Center for Excellence in Optical Data Processing, and Computing Systems Center. Applicants should have a PhD in Electrical Engineering or a related field. Carnegie Mellon University is an

equal opportunity affirmative action employer and welcomes applications from women and minority groups. Applicants should submit a resume, a one page statement of research accomplishments and future plans, and up to three of their most significant conference or journal publications to: Professor Robert M. White, Head, Department of Electrical and Computer Engineering, Carnegie Mellon University, Pittsburgh, PA 15213.

Dean, School of Engineering, Mercer University. Mercer University invites applications and nominations for the position of Dean of the School of Engineering. Founded in 1833, Mercer is a Baptist-related, comprehensive university comprised of seven colleges and schools. With a first priority commitment to teaching excellence and a second priority to research, the School of Engineering offers an ABET-accredited B.S.E. degree with specialties in Biomedical, Environmental, Electrical, Industrial, and Mechanical Engineering. B.S. degrees in Environmental Systems, Industrial Management, and Technical Communication are also offered. Current undergraduate enrollment is approximately 500. There are also approximately 200 part-time graduate students. We seek an individual with strong academic qualifications commensurate with the rank of full professor in an engineering discipline; a demonstrated capacity for collegial leadership and commitment to excellence in teaching, research, and professional service; significant academic administrative experience with a record of success in sponsored research development, budget planning, resource allocation, and ABET accreditation; a spirit of entrepreneurship and the desire to work with community, industry, government, and professional leaders in the continued development of collaborative relations and external support, and an understanding and appreciation of the religious identity of the University. Applications should include a letter of application, a one-page summary of qualifications, and a full curriculum vitae. Applications should be received by March 1, 1994 for full consideration, although review and evaluation will continue until the position is filled. The desired starting date is July 1, 1994. Minorities, women, and disabled persons are encouraged to apply. Please address inquiries, nominations, and applications to: Dean of Engineering Search Committee, Dr. Aaron R. Byerley, Chair, Mercer University, Administration Building, Room 205, 1400 Coleman Avenue, Macon, GA 31207. Mercer University is an Equal Opportunity/Affirmative Action Employer.

Assistant Professor, Department of Communications, The University of Texas at El Paso. UTEP invites applications for an anticipated tenure-track position in the area of communications at the Assistant Professor level. A doctorate in Electrical Engineering is required. The successful candidate will be expected to participate in teaching of both undergraduate & graduate students & the development of a research program in communications. Anticipated starting date is 09-01-94 & is contingent upon funding. Submit current resume, listing of three references (name, address, telephone), & statement of current career objectives to Dr. Michael E. Austin, UTEP, Dept. of Electrical Engineering, El Paso, TX 79968-0523. Deadline for receipt of resumes is 03-01-94. The immigration status of non-U.S. citizens must be indicated clearly in the application. UTEP does not discriminate on the basis of race, color, national origin, sex, religion, age or disability in employment or the provision of services.

Electrical Engineering Technology: The Pennsylvania State University at Erie, The Behrend College. Applications are invited for a faculty position at the instructor or assistant professor level to teach associate and baccalaureate level technology courses starting Fall 1994. Preference will be given to candidates with an emphasis in factory automation, microprocessors, motors, data acquisition and process control. M.S. in electrical engineering or equivalent with a minimum of six years industrial experience required, professional registration preferred. Penn State Behrend is a 4-year primarily undergraduate institution within the 22-campus Penn State system. Behrend's technology programs are growing and have the support of local industry. Application deadline is March 15, 1994 or until the position is filled. Send complete resume, official transcripts and the names of three references to Dr. R. Progelhof, Director, School of Engineering and Engineering Technology, Dept. EET 1, The Pennsylvania State University, Erie, PA 16563-0203. An equal opportunity/affirmative action employer. Women and minorities are encouraged to apply.

South Dakota State University: The Department of Electrical Engineering invites applications for a tenure track faculty position at the assistant professor level starting in Fall 1994. Candidates are required to have a Ph.D. in electrical engineering, demonstrated expertise in energy conversion, and effective English communication and interpersonal relations skills. Preferred candidates should have relevant industrial experience, BSEE degree from an ABET-accredited program, full-time teaching experience in an ABET-accredited program, demonstrated effective teaching skills, a strong research record, and potential for developing externally funded research. A strong background in microcontrollers/computers with experience in power-related applications is desired. Other preferred supporting areas include: industrial, process, and real-time controls; and data acquisition/interfacing. Responsibilities will involve undergraduate/graduate advising and teaching, including energy conversion course and laboratory. Application deadline March 15, 1994 or until position filled. For an application form, contact by mail or Fax: Search Committee, Department of Electrical Engineering, Box 2220, SDSU, Brookings, SD 57007-0194; Fax (605) 688-5880. SDSU is an AA/EEO Employer/ADA Reasonable Accommodations (605) 688-4128 (TT/Voice (605) 688-4394).

Texas A&M University. The Electrical Engineering Department expects to have several openings for tenure track faculty at all ranks. Applicants must have a Ph.D degree or completion of all requirements by date of hire. For senior positions, applicants should have a proven record of scholarly contributions, and for junior positions, demonstrated potential for quality research and teaching is necessary. The salary is competitive and commensurate with qualifications and experience. Applicants are sought in the areas of computer engineering, microelectronics, power electronics and signal processing. Applicants should send a complete resume, including names and addresses of three references to Dr. A. D. Patton, Department Head, Electrical Engineering Department, Texas A&M University, College Station, TX 77843-3128. Texas A&M University is an equal opportunity/affirmative action employer and actively seeks the candidacy of women and minorities.

Loyola College: EE assistant prof position expected, full/part time. Department has ABET accredited engineering science program, large MS program, and new EE program. Opportunities for consulting in DC/MD area. Send resume to R.D. Shelton, Loyola College, Baltimore, MD 21210-2699 (M DALEY @ LOYOLA.EDU) AA/EOE.

Research Associate in high-performance solid state systems including VLSI and high-speed devices and circuits. The Signal Propagation Research Lab invites applications for a Research Associate/Lab Manager position. Applicant should have a Ph.D. or strong industrial experience, and demonstrate an outstanding research ability. Annual salary ranges from $30K to $45K. Resumes, reprints of publications, and (3) names of references should be sent to: Professor George W. Pan, Dept. of EECS, P.O. Box 784, Univ. of Wisconsin-Milwaukee, Milwaukee, WI 53201.

University of California at Santa Barbara, Department of Electrical and Computer Engineering. Applications are invited for a tenure-track faculty position in engineering computation, available effective July 1, 1994. The level of the position is open. It is expected that the successful candidate will interact most strongly with faculty in communications, control, and/or signal and image processing, but significant interaction with researchers in computer engineering, computer science, solid state, and wave electronics are also possible and desirable. Specific computational areas of interest include partial differential equations, ordinary differential equations, optimization, wavelets, and stochastic analysis. Normally, completion of a doctorate is required at the time of the appointment. Candidates should have an established research reputation or outstanding research potential, a record of or the ability to attract external research funding, and a strong commitment to teaching at the undergraduate and graduate levels. Applicants should send their resumes and the names and addresses of at least four professional references to: Faculty Search Committee, Department of Electrical and Computer Engineering, University of California, Santa Barbara, CA 93106-9560. Applications will be received until the position is filled. UCSB is an Equal Opportunity/Affirmative Action employer.

Engineering Faculty Position-Robotic Controls System, Colorado School of Mines. The Colorado School of Mines (CSM), Division of Engineering is seeking a tenure-track faculty member with expertise in digital control of robotic systems. Candidates may apply at either the Assistant Professor, Associate Professor, or Professor level. Automated systems and controls is a mainstream area of teaching and research in the CSM Engineering Division. The Division offers interdisciplinary engineering degree programs and conducts interdisciplinary engineering research applied to the energy, materials, resource, and environmental fields. The successful candidate will work with a small existing group of faculty in the Engineering Division which collaborates with additional faculty in Mathematics and Computer Science and Materials Science and Engineering. An appropriate candidate for this position will have credentials demonstrating expertise in the field of digital control for robotic systems. The successful candidate will have interest in the application of contemporary digital computing and actuator mathematical systems and decision processing theory. This expertise will be applied to CSM focus areas in materials, energy, resource production, and the environment. The candidate will have a Ph.D. in electrical engineering, mechanical engineering, or a similar field focusing on digital control of robotic systems, and will be expected to become an outstanding teacher at the undergraduate and graduate levels, and to conduct peer-reviewed research. Undergraduate teaching will include courses such as feedback control, linear systems and circuits, an associated laboratories, as appropriate to the candidate's background. Graduate teaching and research supervision will address the candidate's specific fields of expertise, for example model-based control, non-linear control, control optimization, or telerobotic operator aids. Graduate activities must be consistent with the mission of the proposed CSM graduate program in Engineering Systems. An applications package including at least: (1) letter of application; (2) resume; and (3) names, addresses, phone and fax numbers of three references should be sent to: Colorado School of Mines, Controls Systems Search #94-02-21, Engineering Division, 1500 Illinois Street, Golden, CO 80401 by February 21, 1994. The package should stress proven record or potential of outstanding teaching and research capabilities in digital control of robotic systems. Information from evaluations of teaching effectiveness by peers and former students, lists of reviewed publications, and lists of externally funded research projects would be excellent information to include in the application package, as preference will be given to candidates with these demonstrated credentials. CSM is an AA/EEO employer. Women and minorities are encouraged to apply.

Position Available: The University of Tennessee at Martin is accepting applications for Dean of the School of Engineering Technology and Engineering. For further information contact: Dr. Earl Norwood, Chair, ET&E Search Committee, 102 Fine Arts Building, UTM, Martin, TN 38238. EEO/AA/Title IX/Section 504/ADA Employer

Faculty Positions in Electrical Engineering, UAE University. The EE Department invites applicants for several Faculty Positions. Areas of interest include: Electronics Engineering, Communications Engineering, Power Electronics, Systems and Control Engineering and Solid State Electronics. Candidates with previous academic and industrial experiences are preferred. In addition to regular teaching and service responsibilities, the faculty member in this position is expected to build a strong research program in his area of special-

Engineering, Electrical Engineering, Industrial Engineering, Operations Research, or a related field. Applicants should submit a resume and the names and addresses (including fax and e-mail) of three references to: Search Chairman, Department of Systems, University of Pennsylvania, 220 S. 33rd Street, Philadelphia, PA 19104-6315. The University of Pennsylvania is an equal opportunity/affirmative action employer.

University of Washington. The Department of Electrical Engineering has a tenure-track position, at the Assistant Professor level, for the 1994-95 academic year. The department has an outstanding faculty, a history of interdisciplinary collaboration, and a tradition of excellence. Ten of the current faculty have been awarded the NSF National Young Investigator Award, and one has received an NIH Research Career Development Award. Our research funding has increased more than five fold in the last decade. We are also involved in the NSF ECSEL Coalition to develop innovative new engineering curriculum for undergraduate education. In the summer of 1994, we will break ground on a new 320,000 sq. ft. building to be shared with the Department of Computer Science and Engineering. The department has research focus areas in: Communications, Sensors, Integrated Circuits, Imaging, Robotics, Electromagnetics, Optics, and Energy. Applications are invited from highly qualified, research-oriented candidates with creative teaching skills. Send resume with names of three references to Faculty Search Committee, Department of Electrical Engineering FT-10, University of Washington, Seattle, WA 98195. Applications will be accepted until April 15, 1994, or until the position is filled. The University of Washington is an equal opportunity/affirmative action employer. Women and minorities are encouraged to apply.

Faculty Positions in Electrical Engineering - Should have Ph.D. in EE and experience in Maharishi's TM Sidhi program. Women and minorities encouraged to apply. Send resume to Dr. Claude Setzer, EE Dept. Chair, Maharishi International University, 1000 N. 4th St. DB1029, Fairfield, IA 52557.

Assistant Professor, Department of Mechanical Engineering, The University of British Columbia. "Industrial Automation" - Applications are invited for a tenure-track position at the rank of Assistant Professor in the Department of Mechanical Engineering at the University of British Columbia. Initially, the appointee's research activities will involve development and integration of advanced industrial control, computer vision, and sophisticated electromechanical devices for industrial

Applicants are expected to have a Ph.D. or equivalent degree in electrical engineering or physics and experience in the general areas of wave propagation and scattering, statistical signal analysis, and scientific computation. Experience in the specific areas of time-delay estimation, beamforming, and inverse scattering problems is desirable. The annual salary is $30,000 or higher, commensurate with qualifications. The deadline for application is 30 April 1994. The appointment is to begin on or about 1 January 1995. Please submit your curriculum vitae, a concise (4 pages or less) description of your research interests, and material (reprints or preprints) demonstrating research accomplishments, as well as arrange for at least three letters of recommendation to be sent to Professor Robert C. Waag, Department of Electrical Engineering, Hopeman Hall, University of Rochester, Rochester, NY 14627. The University of Rochester is an Equal Opportunity Employer (M/F).

Computer Engineering: The University of Bridgeport Department of Computer Science and Engineering invites applications for two tenure track positions for the fall 1994 semester. A Ph.D. in computer or electrical engineering, a strong interest in undergraduate and graduate teaching, and an interest in interdisciplinary project development is required. Areas of specialization should include at least one of the following: computer communication, parallel processing, real-time systems, and computer architecture. A demonstrated ability in, or potential for, independent research is important. The Department has two workstation labs composed of HP/Apollo and Sun workstations. A Solboume 700 serves the Suns and PCs over an ethernet backbone. Rank and salary are commensurate with qualifications. Interested applicants should send their resumes and the names and addresses of at least three references to: Prof. Stephen Grodzinsky, Chair, Computer Science and Engineering, University of Bridgeport, Bridgeport, CT 06601 or grodzins@cse.bridgeport.edu. Applications will be reviewed on a rolling basis until the positions are filled. Equal Opportunity Employer.

The Information and Electronics Research Institute (IERI) at Korea Advanced Institute of Science and Technology (KAIST) invites applications for several Postdoctoral positions in the area of Electrical Engineering and/or Computer Science. IERI is an organization within KAIST supporting the research activities of professors in the Department of Electrical Engineering, and the Department of Computer Science. Applications are invited all year round but will be reviewed in March and September of each year. Salary is

onth paid in Korean currency. nducting research with one of the uiding research activities of grad- n the average, the commitment ear. Please submit resume to Dr. , Information and Electronics te, Korea Advanced Institute of chnology, 373-1, Kusong-Dong, on, 305-701, Republic of Korea.). E-mail: dkkim@eekaist.kaist.ac.kr or st.ac.kr

osition. Virginia Tech Center for esearch invites applications to fill culty position. The position will be associate professor level in Civil artment, with a starting date in fall s should have earned a Ph.D. in r mechanical engineering or a ated field with a specialty in the ced Vehicle Control Systems nced Traffic Management Sys- The candidate should have a nd in areas such as, advanced and communication technolo- propulsion systems, automatic n, artificial intelligence, and com- The candidate will be primarily establishing strong relationships us departments of the University, and federal agencies and con- in the area of AVCS and ATMS. this position include teaching nd graduate courses in trans- ering, developing a progressive urriculum that will address the and supervising graduate and tudents. The candidate should strong publication record in the related areas in archival journals, experience in the preparation and management of research projects, ability to interact well with federal, state and local transportation agencies, and an outstanding academic record. The candidate should have excellent oral and written communication skills. Practical experience in public or private transportation related jobs is desirable. Virginia Tech Center for Transportation Research has recently been designated as one of the three national IVHS Research Centers of Excellence by the Federal Highway Administration (FHWA). As part of the designation, the Center for Transportation Research has received a multi-million dollar grant for research and intends to establish an IVHS Master's degree program in the College of Engineering. The Center functions as an innovative and progressive research group conducting cutting edge research in the area of IVHS. Among its research sponsors are FHWA, US Department of Transportation, Virginia Department of Transportation, AT&T, TRW, SRI, and a wide range of other public and private companies and agencies. Qualified applicants should send a current resume along with the names, affiliations and telephone numbers of at least three references before April 15, 1994 to: Dr. Antoine G. Hobeika, Director, Center for Transportation Research, FHWA IVHS Research Center of Excellence, Virginia Tech, 106 Faculty Street, Blacksburg, Va 24061-0536. Virginia Tech is an equal opportunity/affirmative action employer. Women and minorities are encouraged to apply.

The University of Akron: Department of Electrical Engineering invites applications for two tenure-track faculty positions at the assistant or associate professor ranks. Required areas are (1) Power Electronics and Motor Drives (2) Computer Networking and Communications. Applicants must have a doctorate in electrical or computer engineering and will be evaluated based on effective teaching, ability to improve the growing graduate program and potential for initiating funded research. Applications will be reviewed monthly until the positions are filled. Send resume, transcripts and a list of three references to: EE Search, Department of Electrical Engineering, The University of Akron, Akron, OH 44325-3904. The University of Akron is an Equal Education and Employment Institution.

Faculty Position, The Institute of Optics, University of Rochester. The Institute of Optics invites applications for a tenure-track position as an Assistant Professor or Associate Professor of Optics. A Ph.D. degree in Physics, Optics, Electrical Engineering, or a related field, is required. The successful candidate will be expected to teach at

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University, Pittsburgh, PA 15213.

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and the desire to work with community, industry, government, and professional leaders in the continued development of collaborative relations and external support, and an understanding and appreciation of the religious identity of the University. Applications should include a letter of application, a one-page summary of qualifications, and a full curriculum vitae. Applications should be received by March 1, 1994 for full consideration, although review and evaluation will continue until the position is filled. The desired starting date is July 1, 1994. Minorities, women, and disabled persons are encouraged to apply. Please address inquiries, nominations, and applications to: Dean of Engineering Search Committee, Dr. Aaron R. Byerley, Chair, Mercer University, Administration Building, Room 205, 1400 Coleman Avenue, Macon, GA 31207. Mercer University is an Equal Opportunity/Affirmative Action Employer.

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...commodations (605) 688-4128 (TT/Voice (605) 688-4394).

Texas A&M University. The Electrical Engineering Department expects to have several openings for tenure track faculty at all ranks. Applicants must have a Ph.D degree or completion of all requirements by date of hire. For senior positions, applicants should have a proven record of scholarly contributions, and for junior positions, demonstrated potential for quality research and teaching is necessary. The salary is competitive and commensurate with qualifications and experience. Applicants are sought in the areas of computer engineering, microelectronics, power electronics and signal processing. Applicants should send a complete resume, including names and addresses of three references to Dr. A. D. Patton, Department Head, Electrical Engineering Department, Texas A&M University, College Station, TX 77843-3128. Texas A&M University is an equal opportunity/affirmative action employer and actively seeks the candidacy of women and minorities.

Loyola College: EE assistant prof position expected, full/part time. Department has ABET accredited engineering science program, large MS program, and new EE program. Opportunities for consulting in DC/MD area. Send resume to R.D. Shelton, Loyola College, Baltimore, MD 21210-2699 (M DALEY @ LOYOLA.EDU) AA/EOE.

Research Associate in high-performance solid state systems including VLSI and high-speed devices and circuits. The Signal Propagation Research Lab invites applications for a Research Associate/Lab Manager position. Applicant should have a Ph.D. or strong industrial experience, and demonstrate an outstanding research ability. Annual salary ranges from \$30K to \$45K. Resumes, reprints of publications, and (3) names of references should be sent to: Professor George W. Pan, Dept. of EECS, P.O. Box 784, Univ. of Wisconsin-Milwaukee, Milwaukee, WI 53201.

University of California at Santa Barbara, Department of Electrical and Computer Engineering. Applications are invited for a tenure-track faculty position in engineering computation, available effective July 1, 1994. The level of the position is open. It is expected that the successful candidate will interact most strongly with faculty in communications, control, and/or signal and image processing, but significant interaction with researchers in computer engineering, computer science, solid state, and wave electronics are also possible and desirable. Specific computational areas of interest include partial differential equations, ordinary dif-

...rary digital computing and actuator mathematical systems and decision processing theory. This expertise will be applied to CSM focus areas in materials, energy, resource production, and the environment. The candidate will have a Ph.D. in electrical engineering, mechanical engineering, or a similar field focusing on digital control of robotic systems, and will be expected to become an outstanding teacher at the undergraduate and graduate levels, and to conduct peer-reviewed research. Undergraduate teaching will include courses such as feedback control, linear systems and circuits, an associated laboratories, as appropriate to the candidate's background. Graduate teaching and research supervision will address the candidate's specific fields of expertise, for example model-based control, non-linear control, control optimization, or telerobotic operator aids. Graduate activities must be consistent with the mission of the proposed CSM graduate program in Engineering Systems. An applications package including at least: (1) letter of application; (2) resume; and (3) names, addresses, phone and fax numbers of three references should be sent to: Colorado School of Mines, Controls Systems Search #94-02-21, Engineering Division, 1500 Illinois Street, Golden, CO 80401 by February 21, 1994. The package should stress proven record or potential of outstanding teaching and research capabilities in digital control of robotic systems. Information from evaluations of teaching effectiveness by peers and former students, lists of reviewed publications, and lists of externally funded research projects would be excellent information to include in the application package, as preference will be given to candidates with these demonstrated credentials. CSM is an AA/EEO employer. Women and minorities are encouraged to apply.

Position Available: The University of Tennessee at Martin is accepting applications for Dean of the School of Engineering Technology and Engineering. For further information contact: Dr. Earl Norwood, Chair, ET&E Search Committee, 102 Fine Arts Building, UTM, Martin, TN 38238. EEO/AA/Title IX/Section 504/ADA Employer

Faculty Positions in Electrical Engineering, UAE University. The EE Department invites applicants for several Faculty Positions. Areas of interest include: Electronics Engineering, Communications Engineering, Power Electronics, Systems and Control Engineering and Solid State Electronics. Candidates with previous academic and industrial experiences are preferred. In addition to regular teaching and service responsibilities, the faculty member in this position is expected to build a strong research program in his area of special-

ization. The positions are anticipated to be filled beginning September 1, 1994. Please send resume and the names of five references to: Professor H.I. Shahein, Chairman, Department of Electrical Engineering, United Arab Emirates University, Al-Ain, P.O. Box: 17555, UAE. Fax: 0971 3 632 382. Applications will be expected until the end of February 1994.

The Electrical and Computer Engineering Department, University of Michigan-Dearbom has an opening for a faculty position at the Assistant/Associate Professor level starting Fall 1994. The selected candidate is expected to be active in research, and teach graduate/undergraduate courses in analog and digital electronics, power electronics, microprocessor based systems design and design of VLSI circuits. Send resumes to: Chairman, ECE Dept., Univ. of Michigan-Dearborn, 4901 Evergreen Rd., Dbrn, MI 48128, U of M is an equal opportunity educator and employer and specifically invites and encourages applications from women and minorities.

The University of Pennsylvania, Department of Systems. The Department of Systems at the University of Pennsylvania invites applications for junior faculty positions. These tenure-track appointments are planned to begin as early as September, 1994. We encourage Applicants with expertise in Systems Engineering, and who are interested in working in a multidisciplinary department that includes faculty in Telecommunications, Manufacturing, Environmental Systems and Transportation Systems. Applicants are expected to have a strong commitment to excellence in teaching and research, and to rigorously pursue research funding opportunities. They should hold a doctoral degree in Systems Engineering, Civil Engineering, Electrical Engineering, Industrial Engineering, Operations Research, or a related field. Applicants should submit a resume and the names and addresses (including fax and e-mail) of three references to: Search Chairman, Department of Systems, University of Pennsylvania, 220 S. 33rd Street, Philadelphia, PA 19104-6315. The University of Pennsylvania is an equal opportunity/affirmative action employer.

University of Washington. The Department of Electrical Engineering has a tenure-track position, at the Assistant Professor level, for the 1994-95 academic year. The department has an outstanding faculty, a history of interdisciplinary collaboration, and a tradition of excellence. Ten of the current faculty have been awarded the NSF National Young Investigator Award, and one has received an NIH Research Career Development Award. Our research funding has increased more than five fold in the last decade. We are also involved in the NSF ECSEL Coalition to develop innovative new engineering curriculum for undergraduate education. In the summer of 1994, we will break ground on a new 320,000 sq. ft. building to be shared with the Department of Computer Science and Engineering. The department has research focus areas in: Communications, Sensors, Integrated Circuits, Imaging, Robotics, Electromagnetics, Optics, and Energy. Applications are invited from highly qualified, research-oriented candidates with creative teaching skills. Send resume with names of three references to Faculty Search Committee, Department of Electrical Engineering FT-10, University of Washington, Seattle, WA 98195. Applications will be accepted until April 15, 1994, or until the position is filled. The University of Washington is an equal opportunity/affirmative action employer. Women and minorities are encouraged to apply.

Faculty Positions in Electrical Engineering - Should have Ph.D. in EE and experience in Maharishi's TM Sidhi program. Women and minorities encouraged to apply. Send resume to Dr. Claude Setzer, EE Dept. Chair, Maharishi International University, 1000 N. 4th St. DB1029, Fairfield, IA 52557.

Assistant Professor, Department of Mechanical Engineering, The University of British Columbia. "Industrial Automation" - Applications are invited for a tenure-track position at the rank of Assistant Professor in the Department of Mechanical Engineering at the University of British Columbia. Initially, the appointee's research activities will involve development and integration of advanced industrial control, computer vision, and sophisticated electromechanical devices for industrial applications. Teaching at graduate and undergraduate levels will be expected in the areas of control, dynamics and design. Experience in flexible automation and robotics will be useful. Expertise in hardware and software aspects of computer control and in design and development of electromechanical systems will be important. Required qualifications include a Ph.D. degree in a related engineering discipline. The general area of interest is Industrial Automation. There is also the possibility that this appointment will be linked to a Junior Research Chair, sponsored by NSERC (Natural Sciences and Engineering Research Council). In this case research funding will be available, and teaching duties will be reduced, for a period of five years. The position is subject to final budgetary approval. In accordance with Canadian immigration requirements, this advertisement is directed to Canadian citizens and permanent residents of Canada. UBC welcomes all qualified applicants, especially women, aboriginal people, visible minorities, and persons with disabilities. Closing date for application is March 31, 1994. Please send complete curriculum vitae stating citizenship or visa status, reprints (about three) of your best research publications, and the names, addresses, and telephone numbers of three references to: Head, Department of Mechanical Engineering, The University of British Columbia, 2324 Main Mall, Vancouver, B.C. Canada V6T 1Z4.

Postdoctoral Research Associate. A position is available for an individual with a strong academic record to play a key role in a group carrying out measurements, analyses, and modeling of acoustic wave scattering and propagation in inhomogeneous media for applications in medical ultrasonic imaging and tissue characterization. Applicants are expected to have a Ph.D. or equivalent degree in electrical engineering or physics and experience in the general areas of wave propagation and scattering, statistical signal analysis, and scientific computation. Experience in the specific areas of time-delay estimation, beamforming, and inverse scattering problems is desirable. The annual salary is $30,000 or higher, commensurate with qualifications. The deadline for application is 30 April 1994. The appointment is to begin on or about 1 January 1995. Please submit your curriculum vitae, a concise (4 pages or less) description of your research interests, and material (reprints or preprints) demonstrating research accomplishments, as well as arrange for at least three letters of recommendation to be sent to Professor Robert C. Waag, Department of Electrical Engineering, Hopeman Hall, University of Rochester, Rochester, NY 14627. The University of Rochester is an Equal Opportunity Employer (M/F).

Computer Engineering: The University of Bridgeport Department of Computer Science and Engineering invites applications for two tenure track positions for the fall 1994 semester. A Ph.D. in computer or electrical engineering, a strong interest in undergraduate and graduate teaching, and an interest in interdisciplinary project development is required. Areas of specialization should include at least one of the following: computer communication, parallel processing, real-time systems, and computer architecture. A demonstrated ability in, or potential for, independent research is important. The Department has two workstation labs composed of HP/Apollo and Sun workstations. A Solbourne 700 serves the Suns and PCs over an ethernet backbone. Rank and salary are commensurate with qualifications. Interested applicants should send their resumes and the names and addresses of at least three references to: Prof. Stephen Grodzinsky, Chair, Computer Science and Engineering, University of Bridgeport, Bridgeport, CT 06601 or grodzins@cse.bridgeport.edu. Applications will be reviewed on a rolling basis until the positions are filled. Equal Opportunity Employer.

The Information and Electronics Research Institute (IERI) at Korea Advanced Institute of Science and Technology (KAIST) invites applications for several Postdoctoral positions in the area of Electrical Engineering and/or Computer Science. IERI is an organization within KAIST supporting the research activities of professors in the Department of Electrical Engineering, and the Department of Computer Science. Applications are invited all year round but will be reviewed in March and September of each year. Salary is about $1,200/month paid in Korean currency. Duties include conducting research with one of the professors and guiding research activities of graduate students. On the average, the commitment term is for one year. Please submit resume to Dr. Choong-Ki Kim, Information and Electronics Research Institute, Korea Advanced Institute of Science and Technology, 373-1, Kusong-Dong, Yusong-Gu Taejon, 305-701, Republic of Korea. Fax(82)-42-869-8500. E-mail: ckkim@eekaist.kaist.ac.kr or ckkim@expo.kaist.ac.kr

Tenure Track Position. Virginia Tech Center for Transportation Research invites applications to fill a tenure track faculty position. The position will be at the assistant/associate professor level in Civil Engineering Department, with a starting date in fall 1994. Candidates should have earned a Ph.D. in civil, electrical or mechanical engineering or a transportation related field with a specialty in the area of Advanced Vehicle Control Systems (AVCS) or Advanced Traffic Management Systems (ATMS). The candidate should have a strong background in areas such as, advanced sensing, control and communication technologies, power and propulsion systems, automatic control, simulation, artificial intelligence, and computer modeling. The candidate will be primarily responsible for establishing strong relationships among the various departments of the University, private industry and federal agencies and conducting research in the area of AVCS and ATMS. Other duties of this position include teaching undergraduate and graduate courses in transportation engineering, developing a progressive transportation curriculum that will address the needs of IVHS, and supervising graduate and undergraduate students. The candidate should demonstrate a strong publication record in the related areas in archival journals, experience in the preparation and management of research projects, ability to interact well with federal, state and local transportation agencies, and an outstanding academic record. The candidate should have excellent oral and written communication skills. Practical experience in public or private transportation related jobs is desirable. Virginia Tech Center for Transportation Research has recently been designated as one of the three national IVHS Research Centers of Excellence by the Federal Highway Administration (FHWA). As part of the designation, the Center for Transportation Research has received a multi-million dollar grant for research and intends to establish an IVHS Master's degree program in the College of Engineering. The Center functions as an innovative and progressive research group conducting cutting edge research in the area of IVHS. Among its research sponsors are FHWA, US Department of Transportation, Virginia Department of Transportation, AT&T, TRW, SRI, and a wide range of other public and private companies and agencies. Qualified applicants should send a current resume along with the names, affiliations and telephone numbers of at least three references before April 15, 1994 to: Dr. Antoine G. Hobeika, Director, Center for Transportation Research, FHWA IVHS Research Center of Excellence, Virginia Tech, 106 Faculty Street, Blacksburg, Va 24061-0536. Virginia Tech is an equal opportunity/affirmative action employer. Women and minorities are encouraged to apply.

The University of Akron: Department of Electrical Engineering invites applications for two tenure-track faculty positions at the assistant or associate professor ranks. Required areas are (1) Power Electronics and Motor Drives (2) Computer Networking and Communications. Applicants must have a doctorate in electrical or computer engineering and will be evaluated based on effective teaching, ability to improve the growing graduate program and potential for initiating funded research. Applications will be reviewed monthly until the positions are filled. Send resume, transcripts and a list of three references to: EE Search, Department of Electrical Engineering, The University of Akron, Akron, OH 44325-3904. The University of Akron is an Equal Education and Employment Institution.

Faculty Position, The Institute of Optics, University of Rochester. The Institute of Optics invites applications for a tenure-track position as an Assistant Professor or Associate Professor of Optics. A Ph.D. degree in Physics, Optics, Electrical Engineering, or a related field, is required. The successful candidate will be expected to teach at

both the undergraduate and graduate levels and pursue a vigorous program of research in optics. The Institute is an academic department offering B.S., M.S., and Ph.D. degrees in Optics and has approximately 120 undergraduate students and 120 graduate students in residence. Please send a letter describing teaching and research interests, a curriculum vitae, and the names of three references to: Professor Dennis G. Hall, Director, The Institute of Optics, University of Rochester, Rochester, New York 14627. The University of Rochester is an Affirmative Action/Equal Opportunity Employer.

Illinois Institute of Technology seeks candidates for a unique, tenured position as the Motorola Professor of Electrical and Computer Engineering. It is expected that the position will be filled by a senior Associate Professor, a Professor, or an Engineer from industry with commensurate qualifications. Candidates must have an earned doctorate in electrical engineering or a related field, and should have a strong background and expertise in telecommunications. The ability to develop a telecommunications center is critical to the position, as is an established research record, and visibility in a major professional society. The ideal candidate should have a combination of academic and industrial experience, or liaison with both. Applicants should send a detailed curriculum vita to: Chair, Faculty Search Committee, Electrical & Computer Engineering Department, Illinois Institute of Technology, 3301 South Dearborn Street, Chicago, Illinois 60616. Illinois Institute of Technology is an equal opportunity affirmative action employer. M/F/H/V

Illinois Institute of Technology Electrical and Computer Engineering Department seeks candidates for a tenure track position at the assistant professor level in the area of power and control. The starting date is for the Fall semester of 1994. Qualifications include an earned Ph.D. in electrical engineering. Previous teaching experience is preferred. Interested parties should submit a complete resume with the names and addresses of three references to: Chair, Faculty Search Committee, Electrical & Computer Engineering Department, Illinois Institute of Technology, 3301 South Dearborn Street, Chicago, IL 60616-3793. Illinois Institute of Technology is an equal opportunity affirmative action employer. M/F/H/V

Vanderbilt University: The Program in Computer Engineering invites applications for a tenure-track faculty at the rank of Assistant Professor, although a higher-ranked position would be possible for exceptionally qualified candidates. Successful applicants will be required to establish a productive research program. The person that we seek must be highly qualified to teach undergraduate computer engineering courses as well as graduate courses in electrical engineering or computer science. We would prefer applications in the area of computer architecture with emphasis in parallel and distributed architecture or embedded systems, although other areas of computer engineering will be considered. Applications should include curriculum vitae, a statement of teaching and research interests and a list of at least three individuals willing to submit letters of reference on request. Send applications to: Arthur J. Brodersen, Director, Program in Computer Engineering, P.O. Box 1628, Station B, Vanderbilt University, Nashville, TN 37235, e-mail: broderaj@vuse.vanderbilt.edu. Vanderbilt is an equal opportunity, affirmative action employer.

Faculty Positions, City College of New York. The Department of Electrical Engineering at the City College of the City University of New York is seeking to fill at least one tenure-track faculty position. Applicants must possess a Ph.D., outstanding academic credentials and a strong commitment to teaching and research. Candidates must demonstrate interest and experience in at least one of the following areas: Computer Engineering; Analog/Digital Circuit Design, Communications, Signal Processing; Control Systems; Image Processing. An outstanding research reputation, with the ability to attract external funding, for senior positions, or a demonstrated research potential, for junior positions, is desirable. Resumes, including recent publications and research interest, and names of three professional references should be sent to: Chair, Department of Electrical Engineering, The City College of CUNY, New York, N.Y. 10031. Deadline for applications is 3/31/93 or until all positions are filled. Duties will include teaching (day and /or evening), research and committee work within the normal course of department operations. Salary range will be $29,931 to $76,228 for 10 months plus 4% increase due 11/1/94. Rank and salary will depend on training and experience. An AA/EEO Employer, M/F/H/V.

Assistant/Associate Professor, Communications/Life Safety/Power Systems for Buildings. North Carolina A & T State University seeks an outstanding individual for the position of Assistant or Associate Professor in the Architectural Engineering Department. The Architectural Engineering department has been in existence for over 50 years. The Architectural Engineering department is an ABET accredited engineering program that is in the School of Engineering. The Architectural Engineering program offers both a bachelors and masters degrees with emphasis in Structural design, Building Environmental System (Mechanical/Illumination/Electrical Systems design), and Facilities Engineering. Applicants must have an earned doctorate in Engineering or a related field. The candidate must have a demonstrated record of teaching and research with professional experience and excellent communication skills. The candidate is expected to teach undergraduate and graduate courses while actively pursuing research and publications in his/her area of expertise. The candidate should have knowledge and experience in two or more of the following areas: signal and communication systems in buildings, digital security and life safety systems, computer-controlled energy management systems, electrical power distribution in buildings, energy engineering for buildings, smart buildings, computer modeling of building systems, computer-aided building systems design, expert systems for engineered building systems, building environmental systems design, and/or engineering management of facilities. A complete position description is available upon request. Rank and salary will be commensurate with education and experience. Applicants are invited to submit a resume and letter of application to: Dr. Peter Rojeski, Chairperson, ARCE Search Committee, Architectural Engineering, 447 McNair Hall, North Carolina A & T State University, Greensboro, NC 27411. Consideration will begin March 1, 1994; the applicant pool will be updated monthly until the position is filled. The preferred starting date is August 15, 1994. NCA&T is an EEO/AA employer.

University of Illinois at Urbana-Champaign, General Engineering. The Department of General Engineering, University of Illinois at Urbana-Champaign, invites applications for one (1) tenure-track faculty position. Candidates are sought who have a strong interest in engineering design with emphasis in one of the following areas: engineering geometry (including virtual reality or geometric modeling for design and manufacturing), large-scale systems (including communication, scheduling, and control interaction), discrete-event systems, or intelligent decision making and control. The appointment will normally be made at the assistant-professor level, but a senior-level appointment may be made in an exceptional case for a person of recognized national and international stature. An earned Ph.D. degree in engineering or allied discipline is required. The candidate must be committed to teaching at the undergraduate and graduate levels as well as developing a high quality, externally supported program of research. Salary is commensurate with education and experience. The proposed starting date is August 21, 1994. The Department has 19 faculty and 600 students at the undergraduate and graduate levels, and research programs in engineering design, engineering geometry, robotics and control, discrete-event systems, design and manufacturing systems, decision making/operations research, genetic algorithms, biomechanics, and nondestructive evaluation. Applications, including a letter of interest, a curriculum vitae, complete publication list, dissertation abstract, undergraduate and graduate transcripts and the names of four references should be sent to: Dr. Thomas F., Conry, Head, Department of General Engineering, University of Illinois at Urbana-Champaign, 104 South Mathews Avenue, Urbana, Illinois 61801; (217-333-2730). In order to ensure full consideration, application must be received by March 15, 1994, though applications will be considered until the positions are filled. Some interviews may be conducted before the deadline, but no finalists will be established before the deadline. The University of Illinois is an Affirmative Action, Equal Opportunity Employer.

Massachusetts Institute of Technology, Department of Mechanical Engineering. The Department of Mechanical Engineering invites the submission of applications for a faculty position in Information Science and Technology to begin in the Fall of 1994. The appointment will be for a tenure track Assistant/Associate Professor. Outstanding senior candidates that strongly fulfill the department's goals may be considered for a tenured position at Associate/Full Professor rank. The successful candidate is expected to conduct research and introduce teaching innovations in the areas of information science and technology. The candidate will contribute to at least one of the following subject areas: product/system design, control systems, fluid and thermal sciences, bioengineering, man-machine systems, applied mechanics, transportation and manufacturing. Applicants must have earned a Doctoral degree in Science or Engineering with experience in engineering systems and information science and technology. In particular, a strong background in multi-disciplinary engineering systems is highly desirable. Interested individuals with applicable industrial experience are encouraged to apply. Applicants should send a curriculum vitae (with citizenship and/or visa status) including a publication list and the names, addresses, and telephone numbers of at least four references. In addition, each applicant must send a one page professional statement describing his/her goals and aspirations at MIT. The statement is important in the selection process. Applications should be sent to the following address, Information Science & Technology Search Chair, Massachusetts Institute of Technology, Department of Mechanical Engineering, Room 3-173, 77 Massachusetts Avenue, Cambridge, Mass 02139. Applications received after April 15, 1994 may not be given full consideration. MIT is an Equal Employment Opportunity/Affirmative Action Employer. Women and members of minority groups are strongly encouraged to apply.

Chairperson, Department of Electrical Engineering, Florida Atlantic University. The College of Engineering at Florida Atlantic University invites applications and nominations for the position of Chairperson, Department of Electrical Engineering. Qualified applicants must possess an earned doctorate in Electrical Engineering or a closely related field, be prominent researchers with a proven record of publications in reputable journals, have excellent leadership skills, administrative and teaching experience. Of special consideration will be the chairperson's demonstrated ability in attracting sponsored research and willingness to work closely with a diverse community of scholars, industrial corporations, and government agencies. Florida Atlantic University is a member of Florida's State University System and is located in Boca Raton on the Atlantic Ocean. The University has experienced a steady growth in student enrollment which currently stands at about 16,000. The location of the University, in an area of thriving economic activity with an unexcelled quality of life attracts faculty and students from all over the world. The College of Engineering is one of nine colleges of the University. The College houses four departments: Computer Science and Engineering, Electrical Engineering, Mechanical Engineering and Ocean Engineering. All departments offer PhD, MS and BS degrees. The sponsored research expenditures of the college for 1992-93 was approximately $7.6M. The College has close ties with many high tech industries in the region including IBM, Motorola, Siemens, and Pratt and Whitney. The Department of Electrical Engineering has 17 regular and 2 adjunct faculty members. Research interests of faculty include robotics and control, communications, electromagnetics, and signal processing. Over 460 undergraduate students, 70 master's students, and 25 doctoral students are presently enrolled in the Department. Applications or nominations should include a statement of interest, curriculum

vitae, and at least three references. Under the "Florida Sunshine Law" all information furnished in the application is accessible to the general public. All applications and nominations must be received by March 15, 1994. All correspondence should be addressed to: EE Chair Search Committee, Department of Electrical Engineering, Florida Atlantic University, Boca Raton, Florida 33431. Florida Atlantic University is an equal opportunity/affirmative action employer. Members of protected classes are encouraged to apply.

Biomedical Image Processing. The University of Akron invites applications and nominations for a joint appointment, tenure-track assistant professor in the Department of Biomedical Engineering and the Department of Electrical Engineering for the fall semester 1994. The faculty member will be expected to teach both undergraduate and graduate courses in signal and image processing and to carry out research in the areas of biomedical image processing. Send resumes and names, addresses and telephone numbers of three references to: Chairperson, Search Committee, Department of Biomedical Engineering, University of Akron, Akron, OH 44325-0302. Applications will be reviewed monthly until the position is filled. The University of Akron is an Equal Education and Employment Institution.

Stanford University, Faculty Openings. Stanford University's Departments of Computer Science and Electrical Engineering seek applicants for a tenure track faculty position in telecommunications software. Applicants should have a Ph.D. in a relevant field, and should have a strong interest in both teaching and research. The appointment will be made at the level of Assistant Professor. Examples of sub-fields of interest include: congestion control, routing algorithms, protocol design, protocol architectures, automated network management and directory services, software for mobile networks, and design and implementation of large scale, reliable software for telecommunications. The successful candidate will be expected to teach courses, both in his/her specialty area and in related subjects, and to build and lead a team of graduate students in Ph.D. research. Stanford University is an equal opportunity/affirmative action employer and especially encourages applications from both minorities and women. Applications, including a resume, a publications list and the names of five references, should be sent by March 31, 1994, to: Professor Fouad Tobagi, Search Committee Chairman, Department of Electrical Engineering, Stanford University, Stanford, CA 94305-4055.

University of Virginia. The Department of Electrical Engineering invites applicants for a tenured or tenure-track faculty position in the areas of communications and signal processing, anticipated for fall of 1994. A tenure eligible applicant must have established a record of research leadership and prominence in his/her field, with a proven ability to secure sponsored research. A junior level applicant must show a strong record in research and publications, and preferably some teaching experience. In both cases, a doctorate in electrical engineering and a strong commitment to excellence in research, teaching, and service are required. Applicants are sought with interests that complement the existing expertise in statistical signal processing, digital modulation and coding, analysis of network protocols, and optical/ microwave communications, and are able to teach courses in these and related areas. Interested individuals should send a complete resume indicating citizenship and, or visa status together with names and addresses of at least four references to: Dr. Robert J. Mattauch, Chairman, Department of Electrical Engineering-CSL, Thornton Hall, University of Virginia, Charlottesville, VA 22903-2442. The search will continue until the position is filled. The University of Virginia is an Equal Opportunity/Affirmative Action Employer.

Rice University, Department of Electrical and Computer Engineering, is seeking imaginative and dynamic candidates with an exceptional record of research accomplishments in the area of electronic materials for the Stanley C. Moore Chair in Engineering. The successful candidate is expected to perform an innovative research program in an area of electronic materials and/or devices which transcends traditional boundaries. Of particular interest is research being performed on the nanometer scale, complementing the newly-announced Nanotechnology Initiative at Rice, the Rice Quantum Institute, and the current Physical Electronics group of the ECE Department. The candidate must also have a strong commitment to teaching at both the undergraduate and graduate level. While it is anticipated that an appointment will be made at the senior level, exceptionally well-qualified applications at all levels will be considered. Candidates should send a resume, including names of references and a research description, to the Chairman, ECE Department, Rice University, Houston, TX 77251-1892. Applications should be received by August 1, 1994. Rice University is committed to attracting qualified persons of diverse backgrounds to its faculty, and is an Equal Opportunity/Affirmative Action Employer.

Government/Industry Positions Open

Electrical Engineer Research and develop key technology and system concepts for spectrally-efficient digital radio frequency data networks such as digital cellular mobile radio telephones, public safety trunked digital radio systems and satellite communications. Research and develop combined modulation and coding concepts for higher spectral efficiency in trunked radio systems and adaptive signal processing algorithms to overcome performance limitations imposed by non-stationary land mobile radio channels. Investigate new metrics for demodulation algorithm control as well as simulation and analysis of the proposed concepts. Coordinate with related business unit. Requirements: Ph.D. in Electrical Engineering, with one year's pre- or postdoctoral research experience in digital communication techniques and signal processing. Two years' independent research experience in analysis and simulation techniques for communication and signal processing methods for data transmission over practical channels. Must have experience with spectral aspects of communication transmission signals. 40 hours/week, $58,500 per year plus standard corporate benefits. Send resumes in duplicate to: New York State Department of Labor, Northway Plaza, Suite 13C, Queensbury, NY 12804, Attn: J. DeDell (Refer to Job Order NY0002777/DOT Code 003.061-010).

Electronics Engineer working in microelectronic design and development. Design advanced analog circuitry for microelectronics. Design mixed signal microelectronics with applications for read-out electronics for medical imaging devices. Conduct research & apply findings in system analysis and front-end signal processing for advanced products. Participate in sensor development and program planning activities for development projects. Implement results of advanced analog circuitry research with subsidiary businesses. Generate new project ideas. Requirements: Ph.D. in Electrical Engineering, with one year's pre- or postdoctoral research experience in microelectronics design. One year experience in conducting advanced analog microelectronics design. Research experience using silicon chips in analog microelectronics design essential. Must have experience using CAD software and VLSI design methodology. 40 hours/week, $58,500 per year plus standard corporate benefits. Send resumes in duplicate to: New York State Department of Labor, Northway Plaza, Suite 13C, Queensbury, NY 12804, Attn: J. DeDell (Refer to Job Order NY0002749/DOT: 003.061-034).

Electronics Engineer. Conduct research & development projects on medical image detectors applied to gamma cameras and positron emission tomography cameras for nuclear medicine. Design and construct detector structures, computer simulate structures, evaluate structures experimentally and implement in commercial medical systems equipment. Evaluate performance of gamma ray collimators, scintillators, dedicated photodetector arrays, and direct X and gamma ray conversion materials. Assist production units in improving testing productivity by computer-assisted methods. Assist subsidiary businesses in implementing research results in medical image detectors, gamma cameras and positron emission tomography cameras and in the generation of new project ideas. Requirements: Ph.D. in Electrical Engineering, 2 years of experience in job or two years' pre- or postdoctoral research experience in radiation effects in solid state devices and circuits. Two years' experience in writing and using numerical simulation tools for electronic devices. Experience in electrical/nuclear engineering experiment design, including circuit design and simulation, essential. Must have experience with radiation safety and health physics in a laboratory setting. 40 hours/week, $53,000 per year, plus standard corporate benefits. Send resumes in duplicate to: New York State Department of Labor, Northway Plaza, Suite 13C, Queensbury, NY 12804. Attn: J. DeDell (Refer to Job Order NY0000360/DOT: 003.061-030).

Engineer, Ultrasound Development, for system level design of diagnostic intravascular ultrasound imaging systems. Apply principals of ultrasound interaction with tissue, system front end signal processing, system digital signal processing, image display characteristics, signal processing algorithms and clinical interaction. Req's Ph.D. in electrical engineering. Experience, research or academic training in: medical diagnostic ultrasound, ultrasound sub-millimeter transducer design, ultrasound time-domain correlation relating to blood flow measurement, analog design and digital design. Position/interview, Sunnyvale. $67,520/year. Send this ad and your resume or letter or qualifications to Job # BA 8002, P.O. Box 269065, Sacramento, CA 95826-9065. EOE.

Electrical and Software Engineer: Computer hardware design of PC mass-storage controllers using off-the-shelf disk controllers, programmable I/0 controllers, DMA controllers and other LSI integrated circuits. Programmable Array Logic designs using single and multiple PALs will be done. Class 0 through Class 4 State Machine design will be performed. Software design for device drivers and production test software will be performed utilizing all functions of BIOS and interrupt support. User interface and full screen edit functions will be created. Assembler and C programs will be written. Disk controllers will be programmed to format, read, and deblock, with CRC and ECC code generation. At least two years of experience required in: Design and test of application specific integrated circuits, error detection and correction, QIC-117 Tape Drives, IBM PC Architecture, 8086 Assembler, 'C' and parallel port based products. B.S. in Electrical Engineering required with at least 2 years experience in job offered. 40 hours per week, 8am to 5pm, $21 per hour. Interview and Job located in Dekalb, Illinois, Must have proof of legal authority to work permanently in the U.S. Send 2 copies of resume to: Illinois Department of Employment Security, 126 S. 4th St, Dekalb, Illinois 60115, Attention: Collier Rutledge Reference #V-IL 10689-B. No calls. An employer paid ad.

Diagnostic Design Engineer for Electronic engine controls/systems engineering services provider; develop test strategies and write low level diagnostic algorithms for engine powertrain applications; develop test plans and test diagnostic algorithms on vehicles; use computer programs such as flow charting, word processing and data base programs to design and test diagnostic algorithms; use data base programs to write test cases and track test results; test system level software and hardware to validate proper operation prior to installation at customer location; Min Qual: Bachelor of Science, Electrical Engineering; 3 yrs exp as electrical diagnostic design tech/engineer; exp must have involved designing and testing diagnostic systems for mechanical and electronic systems, and qual control processes. M-F, 8am - 5pm; $36,385/yr; Employer Paid Ad; Send resume to: Michigan Employment Security Commission, 7310 Woodward Ave., Rm 415, Detroit, MI 48202. REF#92893

Job Title: Senior Pre-Sales Consultant. Job Location: Bellevue, WA. Job Summary: Senior pre-sales consultant is responsible for designing applications software, working with clients to determine needs, consulting with clients at prospect sites, making recommendations concerning applications, demonstrating products, acting as technical resource, and selling product to prospective clients. Requirements: Bachelor's Degree in computer science or accounting. Minimum of five years programming/consulting experience in executive information systems and financial consolidation and reporting programs and a demonstrated background of creating prototypes designed to meet prospects' business needs evidenced by five years of work in a technical, pre-

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Electronic Engineer wanted for microcontroller system design, including Assembly & "C" language development; concepting electronic circuits, designing analog and digital circuits, prototyping electronic designs, testing prototype circuits, designing printed circuit boards using PCAD, developing the packaging, producing drawings using ACAD & written documents describing the electronic design; translating technical documents from Chinese to English and English to Chinese; Reqs. Bachelors in Electronic Technology, 2 yrs exp. in job offered or 2 yrs. related exp. as a Design or Computer Engineer. 2 yrs of related exp. must include design of electronic components. Related exp. or 1 univ. course must have included, in whole or in part, Microcontroller System Design, controlling electronic circuits, designing analog circuits, prototyping electronic designs, designing printed circuit boards using PCAD & writing documents describing the electronic design, programming in Assembly language, developing packaging & producing drawings for electronic components using ACAD; $3,420/mo., $29.60/hr. O.T., 40 hrs/wk. 9a-5p, approx. 5 hrs. O.T. Send resume to 7310 Woodward Ave., Room 415, Detroit, MI 48202. Ref. #88093. "Employer Paid Ad."

Engineer, Process Development: Dev thin film & diffusion process for VLSI fab; improve elec & mech property of dielectric film; dev chem mech polish process for device planarization; dev chem clean process for adv devices. PhD in EE, Elec Mats, Mats Sci or rel field + 6 mo exp in VLSI process eng; or MS + 2 yrs exp in VLSI process eng reqd. $4417/mo. 40 hr/wk. Exp w/VLSI process & cleanroom environ, IC fab chem reaction, & impurity diffusion in semicon reqd. Knlg of thin film characterization, dielectric film, film stress analy, chem mech polish process, & chem clean process for adv device reqd. Job site/intrv: Santa Clara, CA. Send ad & resume to: IEEE Spectrum, Box 2-1, 345 East 47th Street, New York, N.Y. 10017. EOE.

Name of Position: Electrical Engineer, Power System. Job Description: 1. As Transmission Planning Engineer I performs electric transmission system power flow, voltage security and system analysis studies, develop algorithms for advanced computer programs used to study and schedule electric system resource deliveries and develop long-range transmission and substation expansion plans including local areas supplied and the interconnected transmission network located in the upper midwest region of U.S. 2. developing electric transmission and substation expansion studies, 3. performing analysis and documentation of the results of such studies, 4. recommending construction plans for management approval. Min. Ed: Masters of Science in Electrical Engineering. Special Requirements: 1. Proficiency in the use of computers. 2. Proficiency in the use of functional characteristics of power system equipment. 3. Ability to provide adequate documentation. 4. Ability to represent the transmission planning area in joint planning studies with other utilities and departments. 5. Knowledge of Power System Operations. 6. Working knowledge of the following computer languages: Fortran, Pascal and C. 7. Course work must include advanced classes in: a. Computer applications in Power Systems. b. Power System Transient Stability. c. Advanced Power System Stability. d. Application of Computers in Power System Operations. e. Fault Analysis. f. Computational/Linear Algebra. g. Power Systems Relaying. Salary/Conditions: Hours 7:30 a.m. to 4:00 p.m., $3,400.00/month. Any applicant who is interested in this position may apply in writing (send cover letter and resume) to the individual listed below for consideration. All applicants must be authorized for permanent employment in the U.S. in order to apply for the position: Send Resumes to: S. Springmeyer #3-209, MDJT - Room 203, 777 East Lake Street, Minneapolis, MN 55407.

Sr. Process Sustaining Engineer: Perform sustaining engineering for double metal CMOS processes in IC production. Evaluate process manufacturability on current equipment; determine nature of problem; solve it. Set up SPC system; analyze SPC data. Act as liaison to company's European production facilities. Requires: MSEE or Physics + 3 years in CMOS/BiCMOS etch processes. Will also accept BS + 5 years progressive experience in same. Also: Experience with process development; SPC. Hands-on understanding of process manufacturing equipment. Understanding CMOS physics. Experience with and understanding of thin film deposition, planarization methodology, dry and wet etch processes. $50k - $75k/year. Clip ad and send with resume to Rogers & Associates Advertising, Inc., Dept. JY-238, 3032 Bunker Hill Ln., Ste. 207, Santa Clara, CA 95054. No phone calls, please.

Electronic Engineer to design circuitry for security systems, build prototype models using theoretical electronic design principles & demonstrate efficiency. Program microcontrollers & processors using assembly language and C, modeling of circuits, simulation of software & emulation of microcontroller or processor based systems. Utilize emulating system in prototype construction, design analog & digital peripheral circuits, including design & modify circuits complying with customer requirements and specs. Interface with marketing personnel. Require: M.S. in Electrical Eng., 2 1/2 yrs. experience in job offered or 2 1/2 years as Associate Electronics Engineer. Job site Sparks, NV. 40 hour week. Salary $38,000/yr. Please submit resume and a copy of this ad to: # 9327387 Nevada Employment Security Dept., 70 W. Taylor St., Reno, NV 89509-1700.

Special Systems Engineer - Electrical Engineer - BSEE with 8 years experience to join small group of consulting engineers in conceptualizing and design of digital and analogue (signals and voice) systems, including systems integration. Position requires knowledge of plan and specification preparation for bidding and installation in airports, hospitals, and complex university or industrial campuses. The ability to create site-specific highly-reliable generic systems and to translate this information to a set of plans and specifications that can be bid and installed by the appropriate construction trade personnel in the field is paramount. The work includes familiarity with broadband and telephone communications, security systems for access control, fire alarms, energy management, and television using 10 Base T, coax and fiber wiring. Working knowledge of related IEEE and NFPA standards and codes, including the National Electrical Code, is important. Work requires use of Data-Base Management System and computer-aided sketching. Salary range from $40,000 to $52,000. Ross & Baruzzini is a 40-person consulting engineering company located in pleasant surroundings and dedicated to leading-edge technology for mechanical and electrical design in the built environment. Submit resume and preliminary list of references to Carl Hauck, Ross & Baruzzini, Inc., 1304 Baur Boulevard, St. Louis, Missouri 63132. EOE

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Scanning The Institute

The IEEE aids 10 leading Chinese universities

Ten of the top universities teaching electrotechnology in China have been chosen for a pilot program that will give them technical assistance and contact with the outside world of technology. The 10 universities, spanning much of the country, were picked by the IEEE's Transnational Committee in consultation with Texas Instruments Inc. and the IEEE Beijing Section.

Texas Instruments, through its group in Hong Kong, provides the program's "muscle" in the form of a donation of US $12 000 per year for three years, databooks, and collections of commonly used ICs. The cash donation is for setting up an IEEE library of magazines and transactions for each existing or potential IEEE Student Branch at the universities.

The program was officially launched at a one-day conference organized jointly by the Transnational Committee and the Beijing Section last October in Beijing. Involved in the program are the six largest National Societies in China, which include the China Electrotechnical Society, the Chinese Society of Electrical Engineering, and the China Institute of Electronics. The six societies, whose membership may range as high as 300 000, cooperate in an organization called the China Union of Electrotechnology and Information Science and take turns assisting with the running of the IEEE Beijing Section. The IEEE's Beijing Section has about 800 members.

Most members of the national societies and the Beijing Section are relatively senior personnel, according to Paul Y.S. Cheung, a member of the faculty of the University of Hong Kong and chairman in 1993 of the Transnational Committee and Director-Elect of Region 10. Membership dues, generally between $5 and $10 for the Chinese societies, are paid for by members' work units. Monthly salaries are about $100.

"Considering the large engineering population in the country, and their eagerness to join the network of engineers in the rest of the world, the potential development of the IEEE in China is great," Cheung wrote in a report describing the IEEE-university program. He also recommended that a membership drive be started in China jointly with the national societies. If such a program proves successful, it might be extended to other countries, Cheung noted.

Plea for more activity in space

Citing the successful $15-billion-per-year satellite communications industry, the IEEE's U.S. Activities unit in a position paper in late December called for the U.S. government to make a commitment to achieving "the economic promise" of other commercial activities in space.

"Just as we made space the arena of military competition during the Cold War, keen international economic competition compels us to make space the high frontier of commerce and industry," said Charles K. Alexander Jr., chair of the IEEE-USA Board. He noted that commercial activities in space could become profitable if the basic cost of space infrastructure—the companies and technologies needed to design, build, launch, and operate space applications—is brought low enough. The highest national space priority should be given by the government to developing this infrastucture, according to the statement, which also asked that the Federal government:

- Concentrate on increasing the safety and reliability, as well as decreasing the cost, of space activities.
- See to the development of a safer, more reliable and less expensive alternative to the space shuttle.
- Help create large, economically attractive, space-related markets.

Coming in Spectrum

INDIA AND ELECTROTECHNOLOGY. The world's most populous democracy is on the move. With an enormous pool of engineers and technical workers and a growing middle class, India is striving to integrate itself more fully into the world economy. Senior Associate Editor Glenn Zorpette has put together his own first-hand report and analysis of the country's efforts in electronics technology. Coupled with it are separate articles he obtained from major players in the fields the nation deems important, namely:

- Software.
- Nuclear technology.
- Aerospace.
- Telecommunications.
- Electric power.
- Electronics.

MANAGING MULTICHIP MODULES. Two articles or multichip modules (MCMs) will examine what is emerging as the preferred method of fabricating extremely high-speed electronic systems. In one article, an expert from Mentor Graphics Corp. deals with managing the signal integrity in high-speed circuit board and MCM design. The other feature, written by an engineer at Motorola Inc.'s Semiconductor Products Sector, examines the challenges to be surmounted in testing MCMs and describes how to adapt already available chip and board test approaches to the task.

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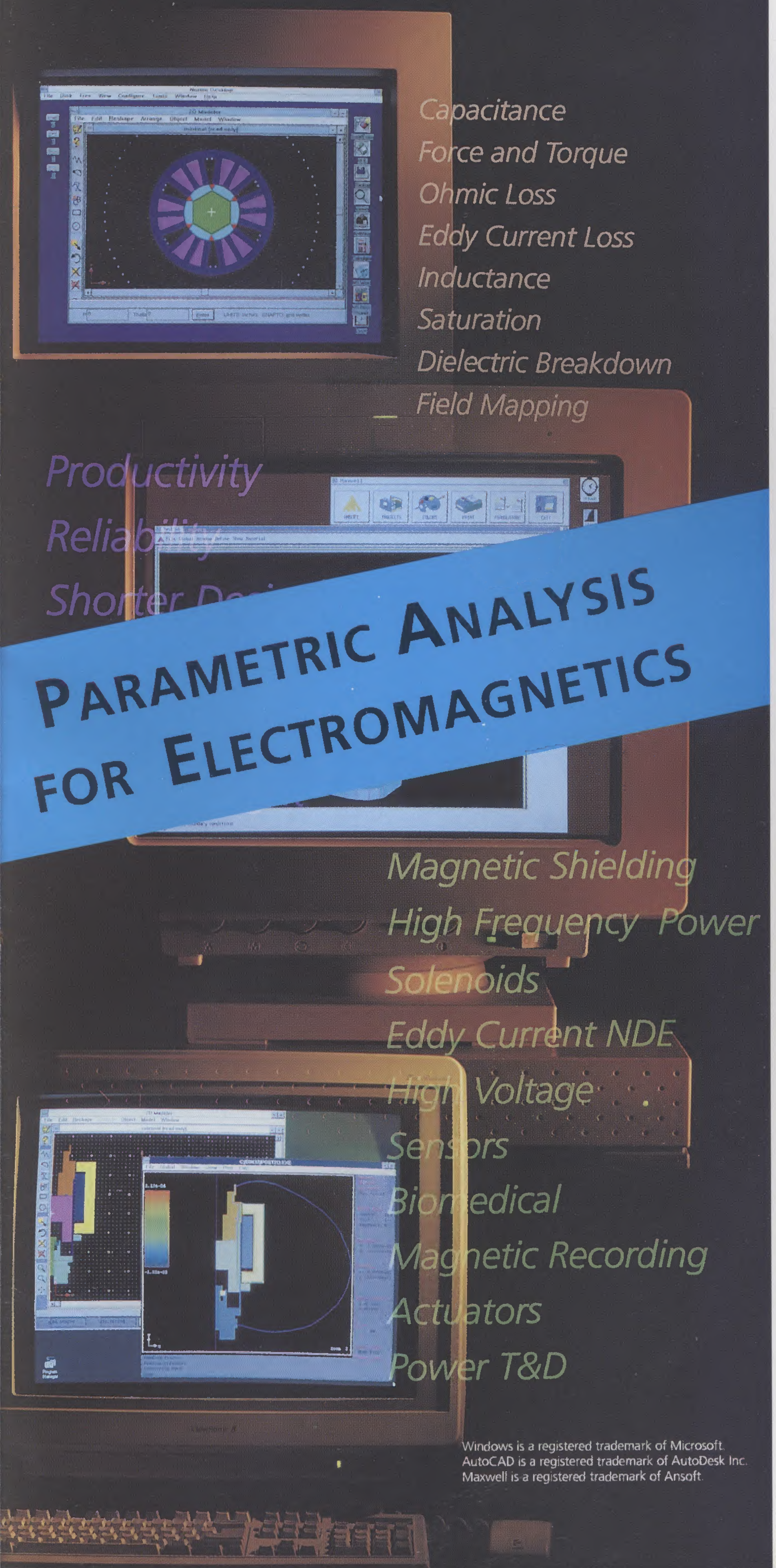

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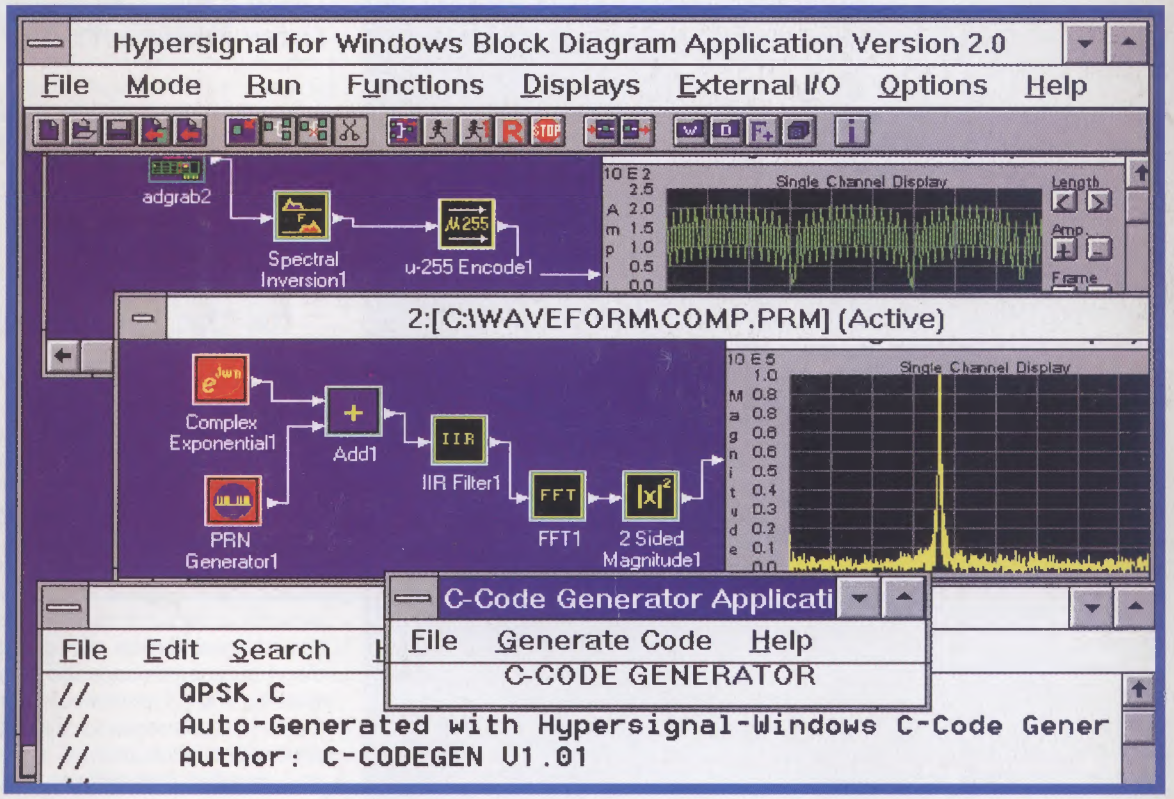

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